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State of California
THE RESOURCES AGENCY
Department of Water Resources

BULLETIN No. 116-5

THE ALASKAN EARTHQUAKE

OCTOBER 1965

HUGO FISHER	EDMUND G. BROWN	WILLIAM E. WARNE
Administrator	*Governor*	*Director*
The Resources Agency	State of California	Department of Water Resources

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The Turnagain landslide, Anchorage, Alaska

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DEPARTMENT OF WATER RESOURCES

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CHAPTER I. INTRODUCTION

Tragedy struck suddenly on a peaceful Good Friday afternoon when south central Alaska was wracked by a violent earthquake. The stunning forces of the earthquake caused extensive damage by severe shaking of structures and by earthquake induced landslides, particularly in Anchorage, the largest city. Large seismic sea waves generated by the earthquake rushed into coastal communities, taking many lives. Submarine slides carried away port and dockage facilities at the seaport communities of Valdez and Seward. Changes in shoreline caused by broad, permanent warping of the earth's crust seriously affected some small coastal communities. Transportation, water distribution, and sewage systems were temporarily disrupted in some areas. Property loss and the detrimental effects on business and industry severly impaired the economy of south central Alaska, and the road to recovery will be difficult, even for the Alaskans, a traditionally hardy breed.

Purpose, Authority and Scope

Unfortunately, much is still unknown about earthquakes despite a constant striving toward a more complete understanding by engineers, geologists, and seismologists. Although some important knowledge has been obtained by laboratory and prototype testing, the study of earthquakes and their effects is not completely amenable to laboratory test and experiment. The most significant advances in earthquake knowledge are made when large earthquakes occur and provide a full scale proving ground for the testing of theory and practice and the opportunity for the observation and evaluation of new phenomena. As a result, progress toward more complete knowledge of earthquakes is spasmodic and is dependent upon the occurrence of major earthquakes. Because many of the major structures in Alaska were built in accordance with current theory and practice for the development of earthquake-resistant structures, the Alaskan earthquake provides an unusual opportunity to evaluate the adequacy or inadequacy of modern design concepts and construction practices.

The State Water Project, currently under construction by the California Department of Water Resources, is a large complex water conservation and conveyance system that carries water from Northern California to Southern California. The system must cross seismically active areas in California, a state whose seismic activity is second only to Alaska. Because of the potential earthquake hazard to the aqueduct system, the Department made special studies to learn more about California earthquakes, and formed a consulting board of experts on

earthquake problems to furnish advice and counsel for the development of an earthquake-resistant system. Realizing that experience gained in the Alaskan earthquake might indicate modification or revision of present Department procedures, Mr. Alfred R. Golze', Chief Engineer for the Department of Water Resources, on June 3, 1964, directed that a small committee be established within the Department to gather and review available information on the Alaskan catastrophe. The committee was assigned the task of preparing a report on the findings of their study, together with recommendations for any modifications of procedures and techniques currently used on the State Water Project.

Mr. J. W. Marlette, Senior Engineering Geologist, was appointed as chairman of the committee on the Alaskan earthquake. The chairman recommended a committee membership representing a number of technical specialities comprised of Messrs. P. L. Clifton, Rehabilitation Measures; H. H. Chan, Structural Engineering; W. M. Gibson, Seismology; B. B. Gordon, Soil Mechanics; and D. M. Hill, Geology. The recommendations for the committee were submitted to Mr. Golze' by memorandum dated June 22, 1964, and were approved. Funding for the investigation was provided for under Work Authority No. 622, "Special Engineering Analysis and Criteria Development".

The committee's assignment consisted of the review and evaluation of available information, and no original work was performed by committee members. Various organizations and individuals still are studying the Alaskan earthquakes, and reports of their completed work may not be available for several more years. As a consequence, this report cannot cover the completed studies, and should be considered as an evaluation of information available at this time.

CHAPTER II. THE ALASKAN SETTING

This chapter provides the reader with a general background of the geology, tectonic history, and economic development of Alaska prior to the Good Friday earthquake.

Geology

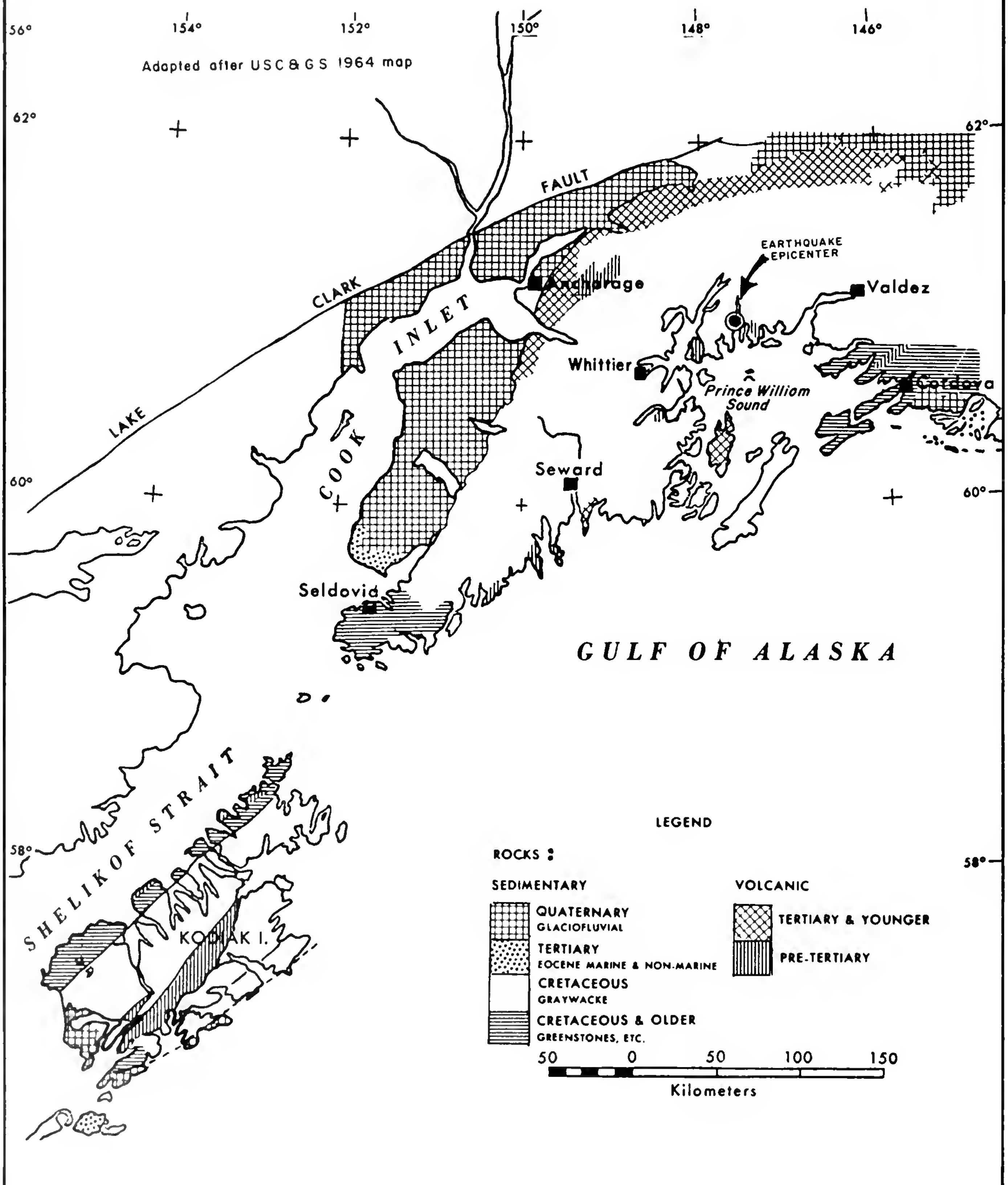
The complex geology of Alaska is not completely mapped, owing to large areas of difficult terrain and short field seasons. Consequently, although the major geologic features are identified, within the State, much of the detailed geology is not completely understood.

The Alaskan landscape is dominated by two major series of mountain ranges; the Brooks Range to the north which crosses northern Alaska in a westerly direction and is slightly concave northward; and the mighty Alaskan Range to the south which is concave to the south. In between the two mountain ranges in the interior portion of Alaska lies a lowland area called the Interior Plateau. Extending north from the Brooks Range to the Arctic Ocean is another lowland area, the Arctic Lowlands. South of the Alaskan Range in a concentric arrangement around the Gulf of Alaska are the Kenai, Chugach, and Saint Elias mountain ranges. Extending off to the southwest in a nearly perfect arc are the Aleutian Islands, where most of the Alaskan earthquakes and volcanoes occur. The Alaskan Range, the mountain ranges bordering the Gulf of Alaska, and the Aleutian Islands, are called the Pacific Mountain System.

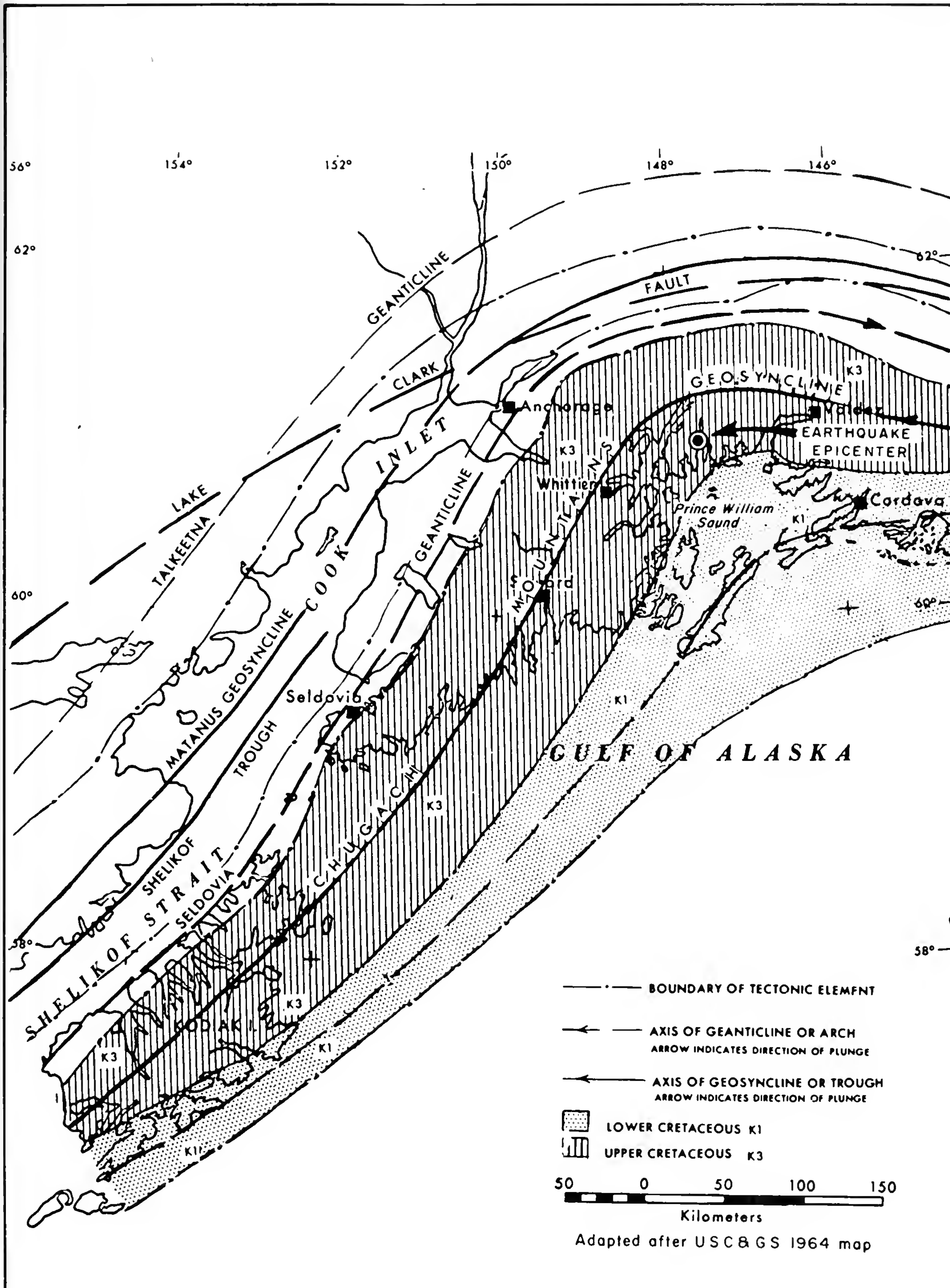
The stratigraphy of Alaska is complex and contains a wide variety of rock types ranging in geologic age from Cambrian to Recent. In southern Alaska, the area of interest in this report, the rocks contained in the mountain ranges are principally slates, shales, argilites, graywackes, and conglomerates that range from Paleozoic to Tertiary in age. General distribution of rock types is shown on Figure 1, entitled "Geologic Map of Epicentral Area".

The southern Alaska landscape has been magnificently sculptured to a rugged grandeur by the work of ice and water, forming rugged mountains and deep, narrow fiords. Waste materials derived from the erosional processes were carried downstream and deposited in lowland areas along major stream valleys, in outwash plains along coastal areas, and in stream deltas in the fiords. Many of the communities are built upon the detritus carried down from mountain ranges bordering the Gulf of Alaska and Prince Williams Sound. These alluvial and glacio-fluvial clays, silts, and gravels generally are poorly consolidated and are prone to landslides and settlement under certain conditions.

The major geologic structures around the Gulf of Alaska are of particular interest in the study of the earthquake. The Pacific Mountain System, bordering the Gulf of Alaska, are



GEOLOGIC MAP OF EPICENTRAL AREA



TECTONIC MAP OF THE EPICENTRAL AREA

formed of sedimentary rocks folded in geosynclinal and geanticlinal structures. Major faults parallel the axes of these major folds in the earth's crust. On the east side of the Gulf of Alaska the general trend of major geologic structures is to the northwest. As shown in Figure 2, these major geologic structures bend around Prince William Sound to a southwest trend, merging with the structural trend of the Aleutian Islands.

The Aleutian Islands have most of the characteristics of a classical island arc in that they are arcuate in plan, have an associated foredeep or trench adjacent to the convex side, have numerous volcanoes, and form a belt of seismic activity characterized by shallow focus earthquakes along the foredeep and deeper, intermediate focus earthquakes underneath the islands. The island chain forms an almost perfect arc 1,400 miles long with a radius of approximately 750 miles. The Aleutian Trench to the south is approximately 15,000 to 25,000 feet deep and 50 to 100 miles wide. Both the island arc and the geologic structures curving around the Gulf of Alaska are considered part of the circum-Pacific tectonic belt, or so-called "Rim of Fire" characterized by many faults, numerous earthquakes, and much volcanic activity.

The manner in which island arcs and their associated foredeeps form, and the reasons for their unusual volcanic and seismic activity are not completely understood, although a number of hypotheses have been proposed to explain the phenomena. Most of the hypotheses for island arc formations ascribe their development to major compressional forces buckling the earth's crust. Because shallow focus earthquakes generally occur in the foredeep, or trench portion, and intermediate focus earthquakes occur underneath the island arc, it is presumed that thrust faults, or high-angle reverse faults have developed underneath the island arcs. At the Aleutian Islands these types of faults should dip in a general northward direction. Tangential fault systems on the islands, presumed by some to provide conduits along which magma moves to the surface, causing volcanic activity, suggest that in addition to compressional folding and thrusting, some rotational movement might be taking place in the island chain. Rotational movement conforms with the hypothesis that the entire area within the circum-Pacific belt is moving in a counter-clockwise direction, causing right lateral displacement around the margins.

The abrupt bending of structural trends from a northwest to southwest direction around the Gulf of Alaska on through the Aleutian Islands, suggests that the forces responsible for the development of the island arc in the earth's crust are impinging upon the continent. Prince William Sound lies roughly at the center of curvature for this structural bending. Regardless of the hypothesis selected for the causes of the geologic structure, Prince William Sound appears to be in an area of considerable stress in the earth's crust.

It should be emphasized that no major fault was mapped at the epicenter, before or after the earthquake, although new secondary faults were mapped on Montague Island after the earthquake. This suggests that interpretation of the visible portion of the earth's crust does not always give a clear picture of tectonic structure and activity throughout the crust and mantle and that regional structure and tectonic history are essential factors to be taken into consideration when evaluating seismic hazard.

Tectonic History

Since 1900, when sufficient seismograph stations were established to obtain a relatively complete history of earthquakes in Alaska, it has become apparent that Alaska is no stranger to relatively large earthquakes. The instrumental records obtained by seismological stations, since the turn of the century, indicate that approximately 4 percent of energy annually released in the world by all earthquakes has an Alaskan source.

As shown in Figure 3, entitled "Alaskan Earthquakes thru March 1964, Magnitude 6-3/4 and Greater", most of the large earthquakes in Alaska occur in a belt along the Aleutian Islands.

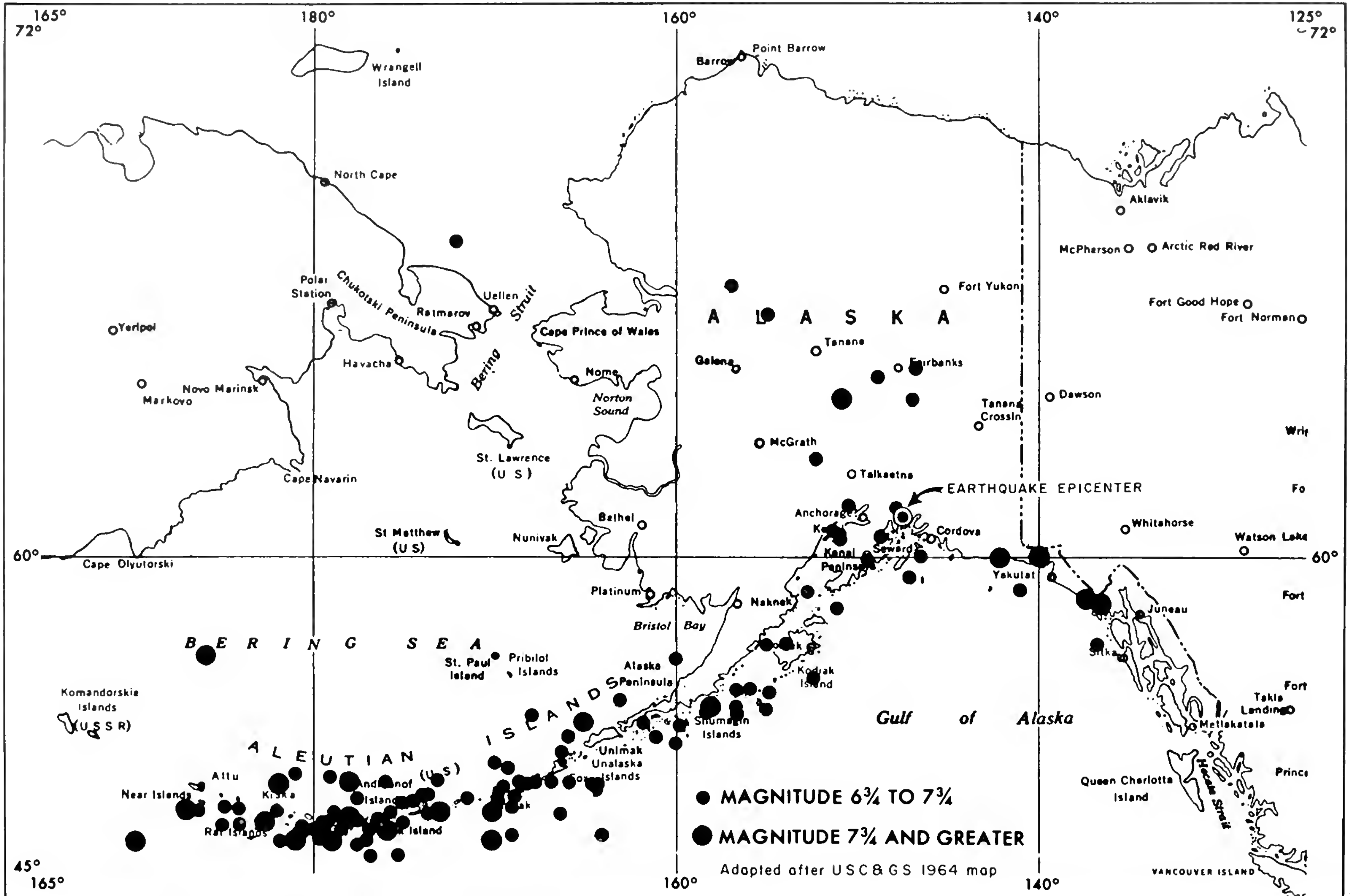
Another earthquake belt extends from the vicinity of Yakutat Bay, southeastward off the west coast of Vancouver Island. Six earthquakes of a magnitude of 6-3/4 or greater also have occurred in the interior portion of Alaska.

A tabulation prepared by the U. S. Coast and Geodetic Survey of earthquakes felt with an intensity of 5 or greater in the Anchorage area since 1788, contains 87 earthquakes. Of these 87 earthquakes, 9, or 10 percent, had instrumental locations of epicenters within 1 degree of latitude and longitude of the epicenter of the Alaskan Good Friday earthquake. A number of the 87 earthquakes tabulated have no instrumental locations for their epicenters, but 4 of the epicenters having no instrumental locations are presumed to have originated in Prince William Sound. In short, 13 out of 87, or 15 percent, of the earthquakes felt in the Anchorage area originated in the Prince William Sound area and 9, or 10 percent, were within 1 degree of latitude or longitude of the epicenter of the Good Friday earthquake. Statistically, the epicentral area in Prince William Sound is a prime source of major earthquakes.

Economy

When Alaska was still a territory, Congress prohibited organization of local governments. As a result, when Alaska became a state, the state government had to take over and operate nearly all services normally handled by smaller governmental

FIGURE 3



ALASKAN EARTHQUAKES THRU MARCH 1964 MAGNITUDE 6¾ AND GREATER

units in other states. Consequently, the Alaska state budget is proportionately larger than other states, and nearly one-half of all personal income in Alaska is derived from state government. The state budget for the 1963-64 fiscal year was reduced by $11 million from the previous year's budget because of extreme reductions in tax revenues. Moreover, a federal transitional grant of $2.4 million annually for a period of five years after statehood, terminated in 1963, causing additional difficulties in getting sufficient funds to provide the required services.

In addition to the economic problems of new statehood, the economy of Alaska has been hampered by the chronic problems of high costs of power, equipment, and labor, the severe climate, and transportation over difficult terrain. Damage created by the earthquake and by seismic sea waves has aggravated these problems, and it is obvious that full economic recovery of Alaska will be a long and difficult process.

Alaska's present population is estimated to be over 265,000. The south central portion of Alaska, the part most seriously affected by the earthquake, contains about 60 percent of the State population and most of this population is centered in Anchorage and its environs. The south central portion of Alaska produces 55 percent of the State's gross product from the basic industries of mining, fishing, and lumbering, and some manufacturing. Military establishments provide some of the economic base, as do commerce and trade at the seaport towns.

Prior to 1940, the Alaskan economy was based on extractive industries, primarily minerals, fish, and furs. However, the Alaskan nonmetallic mineral industries have been transformed during the last two decades from an exporting industry to an industry primarily for domestic use worth approximately $10 million annually. Coal, sand, gravel, and crushed stone constituted the major part of the Alaskan nonmetallic mineral production, until 1961 when petroleum products shot up from 5 to 50 percent.

Approximately 75 percent of Alaska's manufacturing activity consists of fish canning and forest products. The remaining 25 percent is primarily concrete products, printing, publishing, and food processing. Agriculture yields less than 1 percent of the personal income of Alaska.

Alaska imports more than 90 percent of its requirements, primarily because of the heavy requirements of military bases. Almost half of all personal income in Alaska comes from wage and salary payments by federal, state, and local governments.

Buildings

The building development in the city of Anchorage, where the greatest earthquake damage occurred, is much like that of any other western city, with a substantial downtown area and

a large urban development. The finest urban area in the Anchorage District was at Turnagain. This area suffered severe slides during the earthquake, and many homes slid into Cook Inlet. The portion of the city from 4th Street toward the harbor district contained mostly older buildings of flimsily constructed one and two story frame construction and was nearing the time for redevelopment. The buildings were primarily used for pawn shops, bars, and honky tonks.

Schools in the area were generally of one and two story construction. The West Anchorage High School was one of the most modern and beautiful high schools in the United States and suffered severe damage from shaking. The Government Hill School, a frame structure, was completely destroyed by slides.

Population Centers

The following tabulation shows the 1960 population of most of the towns and cities affected by the 1964 earthquake:

Population of
South Central Alaskan Areas
(1960 Census)

Area	Population
Alaska	226,167
Total South Central Districts	103,663
Anchorage Districts	82,833
Anchorage City	44,237
Cordova, McCarthy Districts	1,759
Cordova City	1,128
Kenai - Cook Inlet District	6,097
Kenai	7,174
Kodiak	2,628
Kodiak City	2,956
Seward City	2,844
Valdez	555
Chiquina	31
Whittier	809

CHAPTER III. THE GOOD FRIDAY ALASKAN EARTHQUAKE

Because of the lack of adequate instrumentation, no instrumental data are available on the behavior of the earthquake within Alaska. Although the world-wide network of seismograph stations established magnitude, epicentral location, and focal depth, none of the types of data needed for engineering analysis was obtained. What is known about the earthquake and the ensuing tsunamis and crustal warping is presented in this chapter.

Statistics on the Alaskan Earthquake

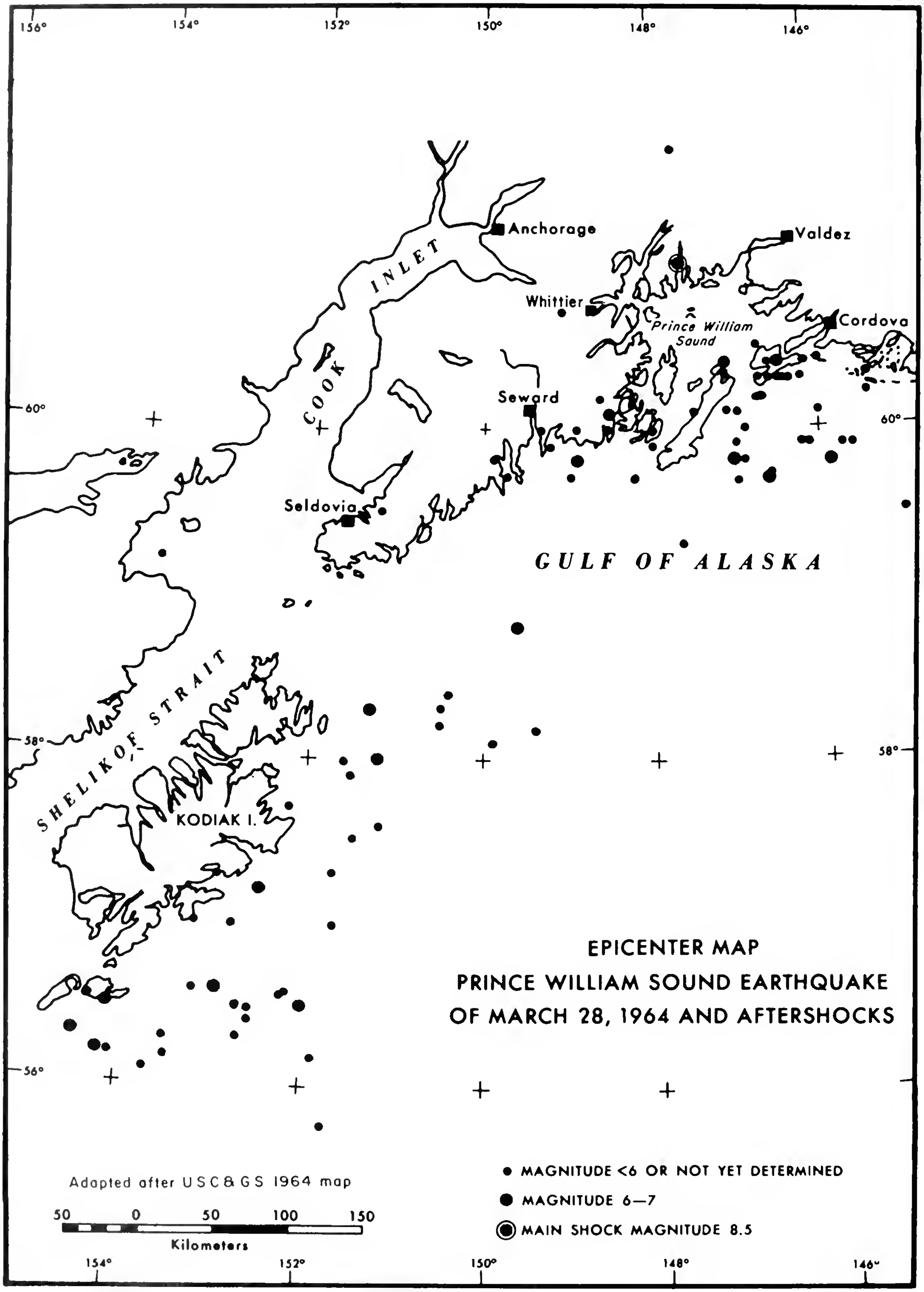
The earthquake occurred at 5:36 Alaskan Standard Time on March 27, 1964. Its epicenter was at 61.10 degrees north latitude and 147.60 degrees west longitude, under land at the north margin of Prince William Sound. The depth of focus originally was estimated to be 20 kilometers, but recent estimates place the focal depth at approximately 60 kilometers. Estimates of the magnitude range from 8.4 to 8.75 on the revised Richter scale, and this earthquake may be the greatest one yet recorded on seismographs. Damage was experienced in an area of approximately 50,000 square miles and the limit of perceptability was 1,000,000 square miles.

The duration of shaking experienced during the Alaskan earthquake was unusually long. The lack of adequate instrumentation made it necessary to make estimates of the duration of shaking from eyewitness accounts. Understandably these accounts conflicted a great deal, but best evidence indicates that the period of strong shaking lasted from 4 to 6 minutes in the Anchorage area. It should be pointed out that the strong motion record of the El Centro earthquake in 1940, frequently used as a basis for design in California, had a duration of approximately 25 seconds.

Anchorage, 75 miles from the epicenter, experienced more vibratory damage than communities closer to the epicenter. For example, Valdez, 45 miles from the epicenter and Whittier, about 40 miles from the epicenter, had little structural damage from earthquake vibrations. Cordova, about the same distance from the epicenter as Anchorage, had little vibratory damage to structures.

Innumerable aftershocks followed the main earthquake and by March 30, 1964, 52 principal aftershocks were recorded of which 11 had magnitudes that exceeded 6 on the Richter scale. The aftershocks generally moved southwestward toward the tip of Kodiak Island, a distance of some 400 miles, although some aftershocks were detected in the area east of Montague Island. The trend of the aftershocks shown on Figure 4, suggests that the rupture of the earth's crust started at the epicenter and moved southwestward in the vicinity of the Aleutian Trench to the tip of Kodiak Island.

FIGURE 4



156°
154°
152°
150°
148°
146°
60°
58°
56°
Anchorage
Valdez
Whittier
Prince William Sound
Cordova
COOK INLET
Seward
Seldovia
GULF OF ALASKA
SHELIKOF STRAIT
KODIAK I.
EPICENTER MAP
PRINCE WILLIAM SOUND EARTHQUAKE
OF MARCH 28, 1964 AND AFTERSHOCKS
Adapted after USC&GS 1964 map
50 0 50 100 150
Kilometers
MAGNITUDE <6 OR NOT YET DETERMINED
MAGNITUDE 6—7
MAIN SHOCK MAGNITUDE 8.5

Crustal Warping

Immediately after the earthquake, coastal communities became painfully aware that large portions of the earth's crust had been elevated or depressed, causing a drastic change in the shoreline. On March 29, the U. S. Coast and Geodetic Survey sent a special tide party from Washington, D. C., to establish new tide control stations in Prince William Sound and vicinity, to reactivate tide stations made inoperative by the earthquake and seismic sea waves, and to inspect, calibrate, and service other tidal stations as conditions would permit. Three survey ships assisted.

Nineteen tide gages were put into operation, and new comparative tidal data derived with reference to nearby undamaged bench marks that had been established prior to the disaster. Through simultaneous comparisons with the tidal data at Sitka, new preliminary tidal planes were determined at 19 reestablished stations. Comparison of the new sea level datums with those before the disaster gave reasonably reliable determinations of land movement with respect to sea level. The changes in elevation at the 19 tide gages are shown on Table No. 2.

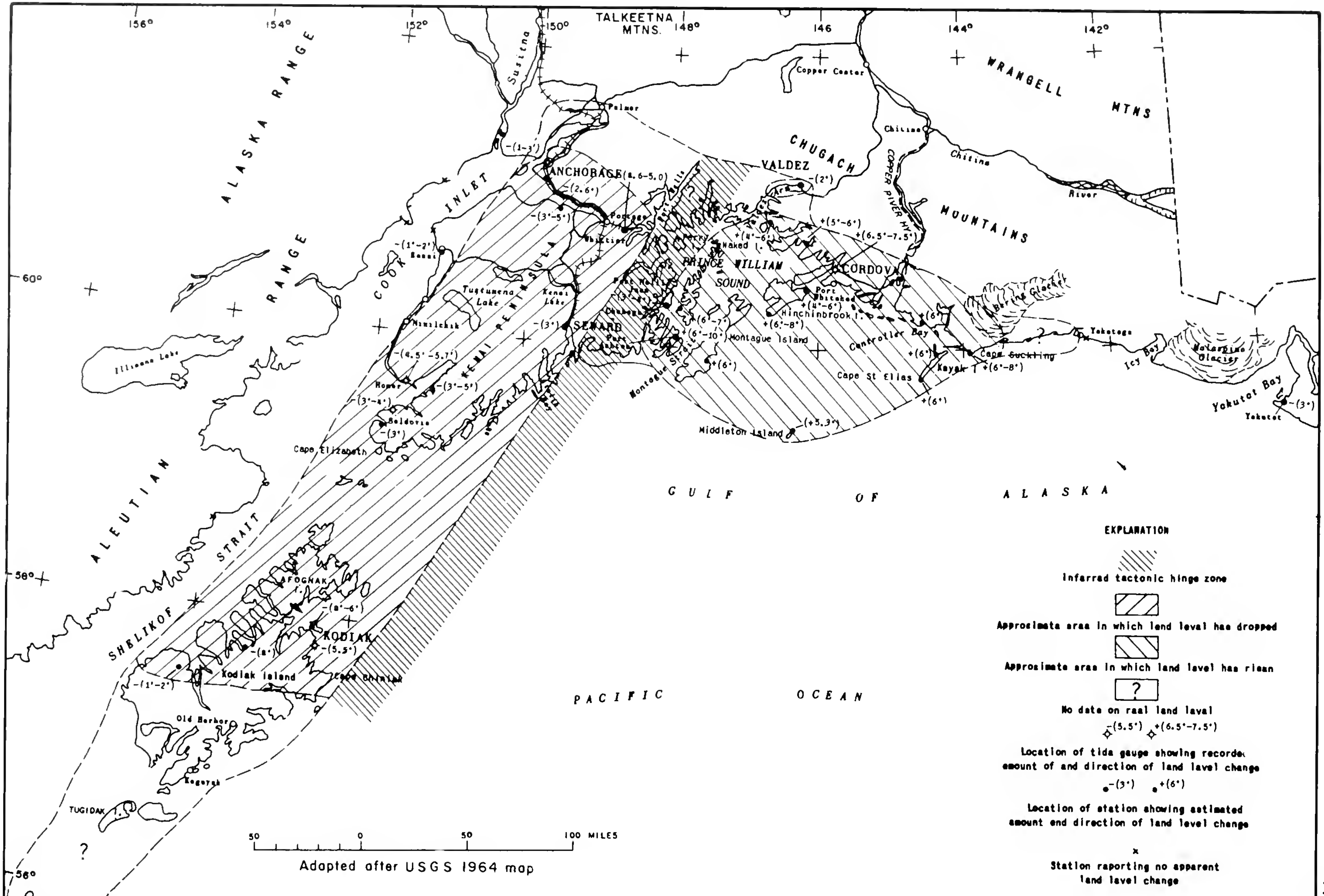
Additional land movements relative to sea level were determined by spirit level as follows:

Location	Land Movement (feet)
Grand Island, Prince William Sound	+7.2
McClead Harbor, Montague Island	+31.5
Patton Bay, Montague Island	+14.9

In addition to the investigations of the U. S. Coast and Geodetic Survey, the U. S. Geological Survey reconnoitered shore lines in the vicinity of the earthquake to note changes in elevation.

Preliminary estimates by the U. S. Geological Survey indicated that 34,000 square miles of the earth's crust was affected by tectonic uplift or subsidence. The original estimate of the area is shown on Figure No. 5. From subsequent studies, not yet concluded, it appears that an area of approximately 600 miles long and 20 to 60 miles wide on the north side of the trench was depressed and an area of approximately 600 miles long and up to 100 miles wide on the southerly side of the trench was uplifted. Rough estimates indicate that approximately 43,000 square miles were affected by subsidence, and 40,000 square miles affected by uplift, making a total affected area of 83,000 square miles, equivalent to approximately half the area of the State of California. Maximum tectonic subsidence indicated by the tide gages was 5.6 feet at Womans Bay on Kodiak Island; whereas maximum tectonic uplift of 33 feet was measured on Montague Island.

FIGURE 5



MAP SHOWING LAND-LEVEL CHANGES ALONG COAST OF SOUTH-CENTRAL ALASKA

Studies made by Press and Jackson of the main shock, the aftershocks, and the residual displacement of the earth's crust, indicate the fault along which the earthquake occurred had a nearly vertical plane and was about 650 km long. They concluded from their studies that the primary fault came to with 15 to 20 km of the earth's crust and extended 100 to 200 km into the earth. Estimated energy released initially was 3×10^{24} ergs, equivalent to a series in line of 100 nuclear explosions of 100 megatons each.

The initial shock and 12,000 aftershocks recorded during a 69-day period after the earthquake are estimated to have released a total seismic energy of 5×10^{25} ergs.

Tsunamis

The March 27 earthquake generated a seismic sea wave that was destructive in the coastal areas and inlets from Kodiak to Valdez. The times of arrival, durations, and maximum rise or fall at 12 tide stations on the west coast and Alaska are given in the attached Table No. 1. The tide gage at Sitka was the nearest one to the epicenter that survived. Excellent records of the seismic sea waves were obtained on the Sitka, San Francisco, Hilo, Los Angeles, Alameda, Astoria, and Freeport, Texas, tide gages. There may be other records but they were not encountered in this study. As all tide gages in the epicentral area were lost, arrival times and maximum highs and lows are not known, except at Kodiak where they were marked and estimated by observers. Waves at Kodiak reached a maximum height of 30 feet above mean sea level.

The seismic sea wave apparently arrived at Cape Chiniak and at Seward about 30 minutes after the main shock. The highest wave to reach Cordova arrived about 7 hours after the initial shock of the earthquake. Greatest damages from tsunamis were experienced in the Alaskan communities of Seward, Whittier, Valdez, and Kodiak; and in Alberni, British Columbia, and Crescent City, California.

A number of other destructive waves were experienced during and following the earthquake at various places in the Prince William Sound area. Some of these at Seward and Valdez were caused by landslides but the cause of the others is not known. Speculation as to the origin of these localized points of wave damage centers around the probability of a strong northward movement of water into Prince William Sound and flows caused by differential vertical movement of the land beneath the waters of the sound. Local shoreline configuration certainly is a factor, and there is strong suspicion that additional submarine landslides might have occurred to cause some of the wave damage. Although areas of damage from waves of unknown origin are small, the wave action was spectacular, having reported wave runups as high as 200 feet above sea level.

TABLE I

Tide Gage Observations of Tsunami
(From U. S. Coast and Geodetic Survey)

	Tide Station	Initial Wave		Maximum Rise or Fall		
		Arrival Time	Initial Rise	Beginning Time	Duration	Heigh
		h--m	feet	h--m	min.	feet
1.	Attu Island	7:30	0.9	20:01	18 F	2.9
2.	Unalaska	6:08	0.3	15:15	12 R	2.6
3.	Sitka	5:08	6.1	6:24	34 R	14.6
4.	Friday Harbor	8:30	1.2	9:52	58 R	2.4
5.	Neah Bay	7:18	3.1	8:40	24 R	4.6
6.	Seattle	9:12	1/2-1 hour Seiche 1/2 ft. off mean curv			
7.	Astoria	7:56	1.9	9:40	10 R	2.3
8.	Avila	8:45	4.4	10:00	9-18 F	11+*
9.	Alameda	9:06	1.5	9:55	27 F	5.5
10.	San Francisco	8:42	2.0	9:34	21 F	7.8
11.	Santa Monica	9:18	2.3	11:18	12 R	6.6
12.	Los Angeles	9:27	0.4	10:06	24 F	3.3

*NOTE: Lower limit reached on gage; 2 hours not recorded.

F = fall
R = rise

TABLE II

Changes in Elevations at Tide Gage Stations

Location	Length of Tide Series	Land Movement (Ft.)
Cordova, Prince William Sound	April 12-July 31, 1964	+6.2
Port Gravina, Prince William Sound	July 3-31, 1964	+4.3
Valdez, Prince William Sound	April 14-July 31, 1964	-0.6
Port Chalmers, Montague Island, Prince William Sound	May 19-30-July 7-Aug. 6, 1964	+10.5
Sawmill Bay, Evans Island, Prince William Sound	May 20-June 1-June 14-July 7, 1964	+7.0
Chenega Island, Prince William Sound	July 7-Aug. 4, 1964	+4.9
Whittier, Prince William Sound	May 1964	-5.3
Seward, Kenai Penisula	May 14-July 31, 1964	-3.5
Seldovia, Cook Inlet	June-July 1964	-3.7
Homer, Cook Inlet	May-June 1964	-5.4
Nikiski, Cook Inlet	June 18-July 31, 1964	-1.5
Anchorage, Cook Inlet	May-July 1964	-3.7
Womens Bay, Kodiak Island	April-July 1964	-5.6
Lazy Bay, Kodiak Island	June 11-30-July 1-Aug. 14, 1964	-0.6
Larsen Bay, Kodiak Island	June 13-30-August 1964	-2.5
Uganik Bay, Kodiak Island	July-August 1964	-3.7
Chignik Bay, Alaska Peninsula	June 19-August 17, 1964	-0.2
Sand Point, Popof Island, Shumagin Islands	June 19-August 18, 1964	0
King Cove, Alaska Peninsula	June 21-August 18, 1964	+0.3

CHAPTER IV. EARTHQUAKE DAMAGE

Less than 10 percent of the land area of Alaska was significantly affected by the earthquake, although 50 percent of the population resided and were employed in the affected area. Fifty-five percent of the State's gross product was derived from the area of earthquake damage. Because of the unfortunate geographic distribution of the population and the economic base around the earthquake epicenter, the earthquake had a serious impact upon both the populace and the economy. This chapter discusses the damage that occurred in south central Alaska.

General

Current estimates place the total earthquake damage in Alaska at $537 million of which $318.6 million is estimated damage to federal, state, and community facilities. The remaining $219 million in damage was to private property. Roughly 50 percent of the total loss is estimated to have been incurred in the Anchorage area. Insured loss has not yet been calculated, but the preliminary estimates place it at about $20 million.

Communities hit hardest by the earthquake, sea waves, or both, were Anchorage, the State's largest city, Seward, Valdez, Kodiak, Whittier, and coastal villages on the Kenai Penninsula and Kodiak Island. Casualities were fewer than might be expected from an earthquake of this size. Most of the casualties were due to seismic sea waves rushing into coastal communities. A total of 115 persons were killed in Alaska, 10 in California, and 4 in Oregon, as a result of the Alaskan earthquake.

Contrary to popular belief, the most severe damage from seismic shocks was not found close to the epicenter of the earthquake. Anchorage, the town most seriously damaged by shaking, was farther from the epicenter than the other damaged communities. On the other hand, Whittier, approximately 40 miles from the epicenter, suffered little damage from seismic shaking, although it was damaged by waves and fire. Inconsistencies also were found in damaged areas where a structure nearly totally demolished from the earthquake might be adjacent to a relatively undamaged structure. The fact that property owned by governmental agencies suffered the greatest loss is somewhat startling, even in view of the fact that governmental agencies own a proportionately larger percentage of property in Alaska than in other states, for it generally is assumed that governmental agencies use conservative standards for design and construction of their facilities.

Illustration 1. Inlet to small boat harbor at Cordova. Picture was taken at high tide and shows result of tectonic uplift on coastal communities.

Illustration 2. Inner harbor at Cordova during high tide.

Landslides and submarine slides were the largest single cause of property damage. Other principal sources of damage were failure of structures by shaking, settlement or deformation of soils underlying the foundations of structures, and the damage caused by the tsunamis or seismic sea waves.

The tectonic uplift and subsidence also will prove costly, because of remedial measures necessary at seaport towns to make port facilities operative again, and because of resurveying needed to correct topographic maps, triangulation stations, and bench marks that are no longer accurate.

News accounts of earthquake damage were focused upon the damage but said little of the lack of damage. As a consequence, many had the impression that the damage approached total destruction. In truth, even in Anchorage, the hardest hit city, estimates of damage ranged around 10 percent. Considering the very large magnitude of the earthquake and the tremendous amount of energy released, it is remarkable that damage was not more severe.

Structural Damage

More flexible structures with long natural periods of vibration, generally experienced more vibratory damage than more rigid, shorter period structures. For example, chimneys on one story houses are short period structures notorious for their vulnerability to earthquake damage, yet in Alaska these suffered little damage. By inference from the behavior of the structures, it is deduced that most of the earthquake energy causing vibration damage was in the long period portion of the earthquake spectrum. It is known that earthquake waves with periods less than 3 or 4 seconds attentuate or die out rapidly with distance, and it is reasonable to assume that these shorter period waves were filtered out by the time the vibrations reached the major cities. The outwash deposits underlying Anchorage appeared to amplify the ground motion because vibration damage seemed more severe there.

The longer period ground motions in Anchorage tended to cause quasi-resonance with tall, flexible, and larger area structures, causing considerable damage to these types of structures. Of course, poorly constructed or poorly designed smaller structures also suffered damage and well-built taller structures experienced little damage or no damage. However, in general, tall structures incurred more damage than short ones.

There were damages to structures having large elevated masses. These masses contributed to the inertial force which had to be resisted by the rest of the structure. The Chugach steam power generating plant located in the Ship Creek section of Anchorage and the power plant at nearby Elmendorf Air Force Base both had large bins connected at the top of the structures. Although differential settlement in the foundation at Chugach probably accentuated the damage, the added mass from the bins caused column buckling and connection failures at this plant and connection damage at Elmendorf.

Illustration 3. Meals building in Valdez (power plant). No damage.

Illustration 4. Post Office in Valdez. No damage.

Railroad and highway bridges were affected by the vibration particularly where the superstructures were simple spans resting on tall flexible piers. Deflections of the piers caused the spans to jack-knife down to the ground.

From the viewpoint of construction materials, structures constructed of lightweight material, such as wood frame units, suffered very little damage as a result of vibration. The greatest damage occurred in structures containing heavy-mass type material such as masonry. Some basic reasons why more damages were sustained by masonry type structures are: (1) inertial forces, as defined by Newton's law of motion, are directly proportional to the mass, and therefore, a structure constructed of a heavier material would have to resist a greater earthquake force; (2) lighter wood structures possess a higher strength to mass ratio than masonry structures; (3) wood structures possess a greater rigidity to mass ratio than masonry structures, consequently masonry structures resonate to longer earth wave periods because of the relatively longer natural periods; and (4) that failure in these heavy materials approaches brittle fracture. Obviously, there are factors beside construction materials that contribute towards structural adequacy of any one structure. Structures of almost any material can withstand large seismic forces, provided they are properly designed and constructed.

Types of foundation played a large role for the structures that resisted the ground motion. At Alaska, it was found that structures properly constructed on piles survived the vibration; whereas those built on spread footings did not fare as well. However, there were some flat slab bridges where the timber piles actually pierced through the deck due to continuous agitation and there were some structures founded on piles where the foundation settled, exposing the piles and stripping them of friction resistance. In the first instance, provision of bent caps probably would have provided more shear resistance. In the second instance, the settlement emphasizes the need for more extensive investigations into foundation problems prior to structural design.

Defects in Design

Hollow concrete block was a common building material used for commercial and industrial structures as well as apartment houses. Much earthquake damage occurred to structures using this type of construction material, because (1) as shown in Illustration 5, there was insufficient reinforcement, or no reinforcement at all to resist seismic forces, and (2) there was insufficient overlap of reinforcement steel to transfer stresses from one bar to another.

A number of structures were damaged because bracings and corner connections either were ignored, or improperly designed to form rigid connections. Failure occurred when the joints were unable to transfer the forces to the proper members for lateral resistance.

Buckling of columns and walls was common. Failures of reinforced concrete columns resulted from omission of ties in

Photograph by J. F. Meehan

Illustration 5. An apartment building in Anchorage constructed mainly of hollow blocks. The damaged blocks showed apparent lack of reinforcement to resist lateral deflections.

Photograph by J. F. Meehan

Illustration 6. Structural failures due to insufficient reinforcement steel and concrete area.

critical areas. Some column failures indicated columns were inadequately designed for compressive strength and had insufficient reinforcement or concrete area.

In other instances, lack of reinforcement and concrete area in column connections to floorings or roofs did not permit the columns to transfer the moments or shear structurally, resulting in fractured columns. This type of failure occurred at the West Anchorage High School. Illustration 6 shows failures resulting from insufficient reinforcement steel and concrete to resist the lateral shear forces.

A large portion of the structural steel column failures resulted from dynamic response and frame behavior. These structures relied on bearing walls to act with the steel frame as a system in resisting the lateral forces. However, investigations showed that these bearing walls, acting also as shear walls, failed initially under prolonged vibration, because they were stiffer than the steel frame. After the walls failed, the entire load of resistance was shifted to the steel frame, overloading and buckling the frame columns.

Relative column stiffnesses played a large role in structural failures as illustrated by the six-story, steel frame Cordova Building at Anchorage. This structure, supported by columns at the first floor, had one single column braced. As distribution of shear loads is proportioned by the ratio of I/L^3, L for the braced column was reduced from 10 feet to about 3 feet which forced the column to take virtually all the lateral load, causing its failure.

In the J. C. Penney Building, precast panels were connected to the steel frame as an exterior wall. During the earthquake, connections between these panels and the steel frame failed when they could no longer restrain the deflections of the frame. This failure was due to the difference in relative stiffness of the two elements and the error in designing the structure to act as a homogenous system to resist lateral forces dynamically. See Illustration 7.

Another type of design failure resulted from inadequate connections between precast elements. A good example was the Alaska Sales and Service Building which was constructed of precast panel walls, and precast "T" beam roof resting on precast reinforced concrete bents. Interconnections between the precast elements were made by means of welded metal connections. After the earthquake, investigations showed that the connections failed causing the walls to collapse or tilt out of plumb. See Illustrations 8 and 9.

Architectural designs resulted in structural failures although they may be classed as minor damages. The heavy parapet walls and other unnecessary gingerbread tore or "became unhinged" from their connections, thereby endangering public safety. The mass of the parapet walls contributes added inertial forces to a structure during vibration, similar to the elevated bins in the power plants at Chugach and Elmendorf.

Illustration 7. The J. C. Penney building in Anchorage.

Photograph by J. F. Meehan

Illustration 8. Connection failure of precast members resulting in separation of wall from roof.

Illustration 9. The Alaska Sales and Service Building in Anchorage is a good example of damage resulting from defective connections in precast concrete construction.

A common type of damage to highway and railroad bridges, was the jamming of the superstructure against the abutment wall. This was due to the inability of the bearings at the abutment to react against the inertial force set up from the mass of the superstructure under motion. The difference in response between the ground motion and the structure also resulted in buckling of the deck structure, and, in certain instances, the end of the deck was lifted from its bearings and ended up overriding the abutment.

Defects in Construction

It is obvious that no matter how well a structure is designed by the engineer, his efforts will be wasted if the structure is not built according to his plans and specifications. Hollow concrete block construction, which was a common material used in structures in Anchorage, suffered greatly from failures that were attributed to faulty construction.

Faulty horizontal construction joints were a source of failure in concrete structures. These damages resulted from negligence in keeping the joints clean before placing succeeding layers of concrete. The foreign particles or dirt left at the joint prevented bonding between each concrete placement, and the concrete, therefore, could not resist the shearing forces.

Improper concrete mix in some reinforced concrete structures resulted in the concrete possessing inadequate compressive strength. Failure occurred when the concrete could no longer withstand the loads resulting from the vibration and causing the concrete to bulge out or "mush out" in a manner similar to column failures resulting from insufficient ties. The plasticity of the concrete caused the tremendous load to be transferred to the reinforcement steel, resulting in a bending failure of reinforcement. An example (showing column buckling of reinforcement steel) is shown in Illustration 11.

A very large percentage of the structural damages were direct results of inadequate quality control of construction and lack of adherence to building codes and specifications. In one case, structural failure was attributed to a revision made after the structure was built by the owner without the advice of the structural engineer. The owner made openings in the shear walls for doors and as a result weakened the lateral resistance of the structure.

Illustration 10. Hollow concrete blocks showing lack of grout in cells.

Illustration 11. Compression failure due to inability of reinforcement to sustain transferred load resulting from plastic flow of concrete.

Damage Resulting From Soil Failures

Soil failures in the form of landslides, submarine slides, and settlement or deformation of foundations under structures was responsible for most of the property damage in Alaska. Most of the property loss in Anchorage resulted from landslides; whereas much of the damage at Seward and Valdez was the result of submarine slides.

Landslides

There were a number of reports of landslides, avalanches, rock slides and lurch cracks throughout south central Alaska, but little detailed information is available on the numerous slides, except in Anchorage. For this reason the slides in Anchorage are the ones covered in this report, although it is recognized that slides occurred in other areas.

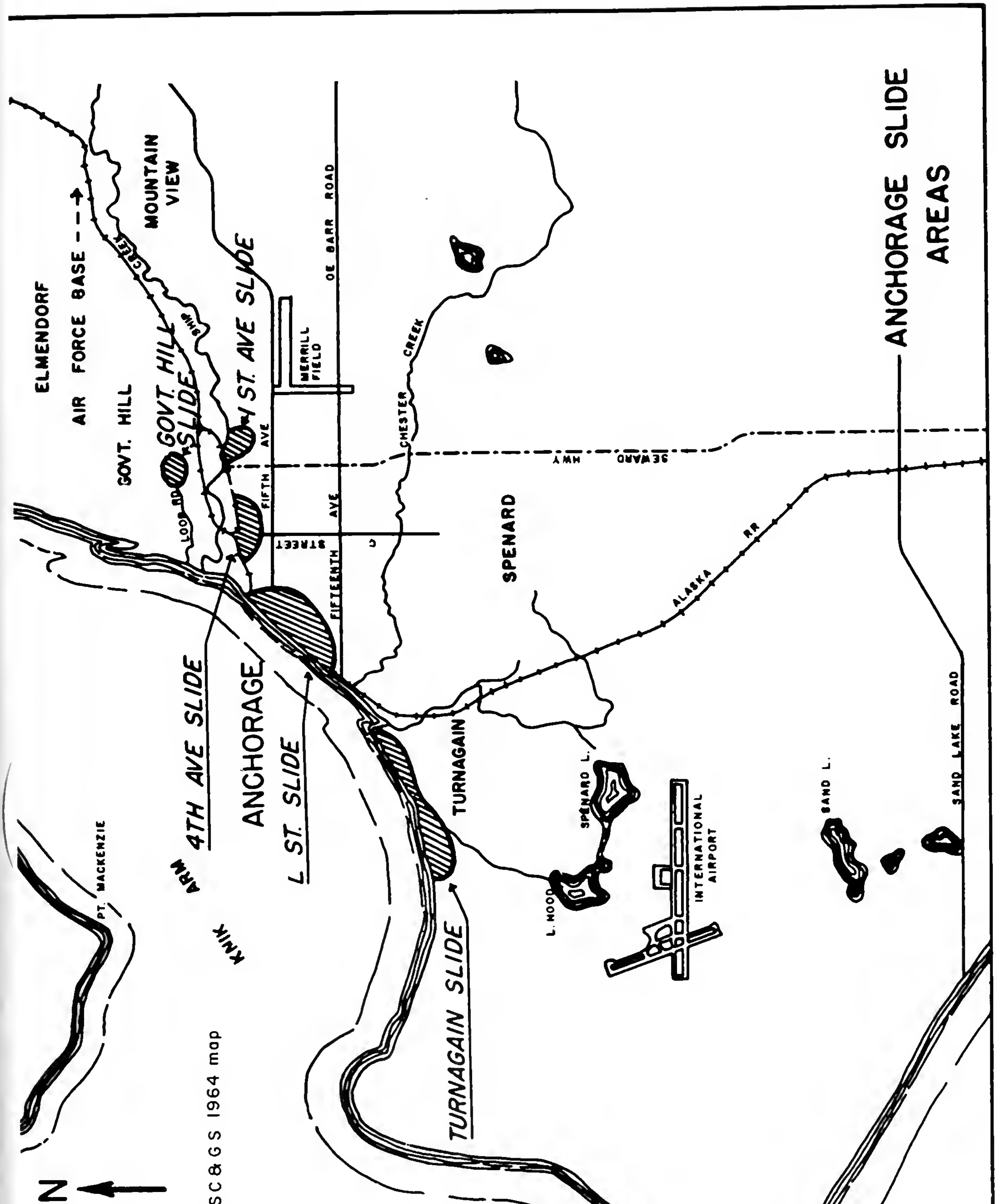
The city of Anchorage is on a plain comprised of glacial outwash material carried down from the high, rugged, Chugach Mountains. Under the city these outwash materials are called the Naptowne outwash, a series of dense sand and gravel deposits, which cover the underlying Bootlegger Cove formation comprised of clay, silt, and fine sand. Soil failures starting within the Bootlegger Cove formation caused most of the Anchorage slides.

Eleven landslides developed in Anchorage during the earthquake. The major slides were: the Fourth Avenue, "L" Street, Turnagain--Romig Hill, First Avenue, Government Hill, and the Ship Creek, and Chester Creek Bluffs.

Because these slides occurred in a highly developed urban area, property damage was high. Damage resulted from the physical displacement of structures, pressure ridges developing at the toes of the slides, and tension cracks, or small grabens, developing at the heads of slides. As near as can be determined, most of the slides did not develop until after a minute or more of earthquake motion, which suggests that the unusually long duration of the earthquake was a major factor in landslide failures. It should be pointed out that the possibility of earthquake-induced landslides developing in the outwash materials underlying the city of Anchorage was recognized before the earthquake and was pointed out in a report put out by the United States Geological Survey in 1959.

Submarine Slides

Both Seward and Valdez are located in narrow fiords and their waterfront areas have been developed on deltaic outwash deposits. Because of the depth of the fiords, the foreset beds of the deltaic deposits are steep, with foreset slopes dipping as steeply as 30 degrees. The steep underwater slopes of the deltas and the type of materials contained in the deltaic deposits made these deposits susceptible to failure during an earthquake. The


ANCHORAGE SLIDE AREAS
ELMENDORF AIR FORCE BASE
MOUNTAIN VIEW
GOVT. HILL
GOVT. HILL SLIDE
1ST. AVE SLIDE
4TH AVE SLIDE
ANCHORAGE
L ST. SLIDE
TURNAGAIN SLIDE
TURNAGAIN
SPENARD
MERRILL FIELD
DE BARR ROAD
CHESTER CREEK
SEWARD HWY
FIFTH AVE
FIFTEENTH AVE
STREET
LOOP RD
ALASKA RR
SPENARD L.
L. HOOD
INTERNATIONAL AIRPORT
SAND L.
SAND LAKE ROAD
KNIK ARM
PT. MACKENZIE
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Adapted after USC&GS 1964 map

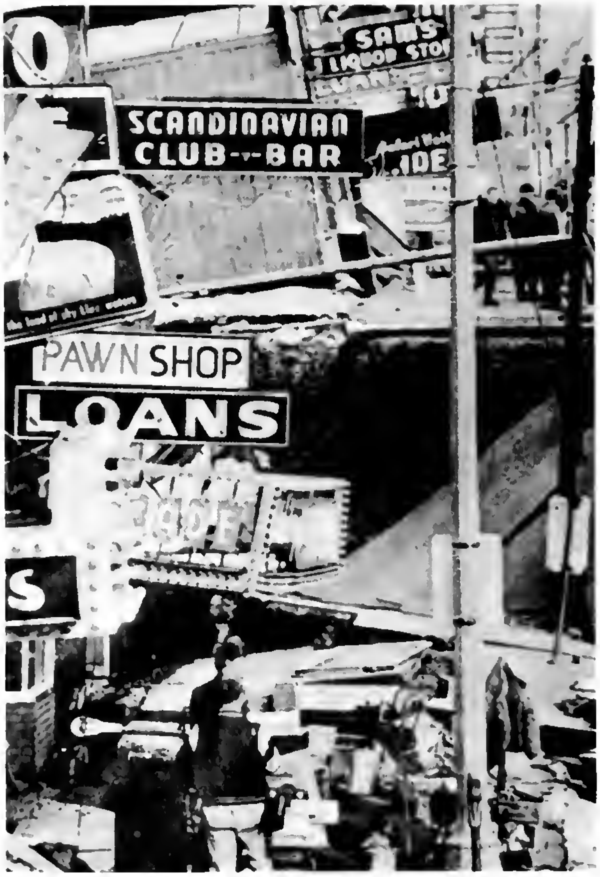

Illustration 12. Fourth Avenue
landslide in Anchorage.

Photograph by J. F. Meehan

Illustration 13. Building damaged by movement of foundation.

Illustration 14. Sag in highway fill near Cordova.

submarine slide at Seward carried away most of the dockage facilities and also affected the shoreline along the adjacent Forest Acres residential area. At Valdez, submarine slides also carried away major port facilities. Because of adverse soil conditions at the old townsite, Valdez will be rebuilt at a new site less susceptible to damage from submarine slides.

Settlement and Foundation Deformation

Damage from settlement of poorly consolidated glacial outwash and other types of alluvial materials were noted in a number of areas. The Copper River highway which traverses approximately 14 miles of bay mud and muskeg near the town of Cordova suffered much damage from settlement and lurching of highway fills on these poor foundation materials. Structures of the Eklutna Project were damaged by settlement of alluvial materials. Settlement of soil combined with tectonic subsidence lowered the seaport town of Homer Spit, causing inundation by the sea, and caused about 5 miles of the Alaskan Railroad to be inundated in the vicinity of Turnagain Arm.

There were a number of reports on damage at other places where settlement or foundation deformation might have been a cause of damage but there was insufficient information to be sure. There can be no doubt, however, that consolidated soils such as those encountered in south central Alaska, are capable of settling or deforming during an earthquake and this type of deformation probably was more prevalent than reports indicate.

Damage to Facilities

Earthquake damage to communication, highway, water supply, and sewage systems and the Eklutna hydroelectric project is of interest because similar facilities though on a different scale, will be used in the State Water Project. With the exception of the Eklutna Project, reports of damage to these types of facilities generally consisted of brief passages in larger reports, news items and brief commentaries in periodicals and professional journals. It is difficult to compile a complete history from these types of information, and the following discussion on damage to various facilities should not be construed as a complete report, but rather a synopsis of damage to facilities.

Communications Systems

Telephone communications in Anchorage were disrupted by the earthquake. Within 2-1/2 hours after the earthquake 30 to 40 percent of the city's telephone system was providing service. Power for the telephone system was provided by standby generators or batteries at the central offices. Seventy-five percent of the circuits within Anchorage were back in service by Saturday, the day

following the earthquake. The fire department communications center had no telephone service for three hours, but both police and fire radio stations remained operative.

In Seward, telephone service was spasmodic for 24 hours after the earthquake. Adequate service was restored after 24 hours. Because of power failure, the telephone communications had to depend on batteries. Eventually, portable generators were flown in by plane to provide power for the telephone system.

In Valdez, telephone systems remained in service except for a two-block strip along the waterfront.

In Kodiak, the central telephone office was flooded, which completely disrupted telephone service. Communications were handled by radio, until telephone service could be restored. By April 30, the telephone company had restored a hundred circuits to operation.

Highway Systems

Highway systems suffered extensive damage. Most of the damage was incurred by bridges or those portions of the highway that went over poorly consolidated fine-grained alluvial materials in river bottom lands and estuaries. Settlement and lateral spreading of the underlying alluvial materials caused much damage to roadbeds and fills. Many of the bridges were totally destroyed or seriously damaged. Many bridges had their abutments move inward, whether on fill or rock, causing a shortening of the length between abutments. Approach fills settled as much as 3 feet. The Alaskan Highway Commission reports that literally bushels of sheared anchor bolts were observed on bridges after the earthquake.

Most recent estimates indicate that damage to roads and bridges may reach as high as $75,000,000. State and Federal agencies managed to get road systems back into operation quickly. Within 15 days after the earthquake, the contract for the construction of a million dollars worth of temporary bridges had been awarded, and the important road connection between Seward and Homer had been reopened to traffic. Complete restoration of road facilities will require a long period of time.

Water Supply Systems

The water supply in the city of Anchorage was obtained from 7 wells. Disruption of power after the earthquake made it impossible to pump from these wells. In addition, 3 of the 7 wells were damaged and have been abandoned. At the time of the earthquake, water supply was by gravity from a water treatment plant at the rate of 3,000,000 gpd. Immediately after the earthquake, the delivery rate jumped to 11,000,000 gpd because of numerous breaks in the distribution system. Even at the 11,000,000 gpd delivery rate, water pressure in the eastern part of the city dropped to zero. About six hours after the earthquake, slides near the treatment plant intake reduced the delivery rate to about 2,000,000 gpd, a rate which

was inadequate to make deliveries through the system, because of losses through the numerous breaks. As a result, the entire city water supply was shut off and gradually restored section by section. Although this left the city without water service for approximately 24 hours, 75 percent of the service was restored by the end of 72 hours.

Examination of failures in the distribution system indicated that there were many failures of bell and spigot joints in cast iron pipe caused by the spigot ramming into and breaking the bell. Where asbestos cement pipe was utilized, the rubber seal rings at the joints were frequently displaced causing leakage. A 24-inch wood stave supply line developed a number of leaks.

Sewage Systems

In Anchorage concrete pipe was used mostly for trunk, lateral, and outfall lines. In addition to pipe ruptures in slide areas, or where pressure ridges developed, other types of pipe damage were noted. Some pipes developed longitudinal cracks along the sides because of excessive vertical pressures or along the top and bottom because of excessive lateral pressures. In either case the pipe was deformed from a circular cross section to an oval cross section. The reasons for the development of excessive vertical or lateral stresses on the concrete pipe were not reported. Other types of failure to concrete pipe were failures of joints on individual pipes, and breaks caused by settlement of backfill. In areas of earth movement, raising of the center portion of a long run of pipe above the hydraulic grade line, resulted in pipe flotation. On one sewer outfall made of corrugated metal pipe, damage consisted of either broken metal connecting bands or displaced seals at the joints.

Damage to sewer lines and the accompanying failure of the water distribution system made the sewage system temporarily inoperative. Human waste disposal units were established and scheduled pickups were in operation the day following the earthquake. The sewage lines were returned to operation at about the same time water service was restored to the various areas.

Dams

Aside from the damage to the dam at the Eklutna Project at Eklutna, nothing was encountered in written reports alluding to damage of dams. According to verbal reports, one small dam failed in the Anchorage area, and transverse cracks developed in a low embankment impounding water for Elmendorf Air Foce Base.

Eklutna Project

The Eklutna Project is a small hydroelectric project owned and operated by the U. S. Bureau of Reclamation approximately 34 miles northeast of the City of Anchorage. Water for the project

is obtained from Eklutna Lake which is impounded by a low earth dam, providing a reservoir capacity of 182,100 acre-feet. Water from the lake is diverted through Goat Mountain in a 4-1/2-mile long 9-foot diameter, circular, concrete lined tunnel, and down through an underground steel penstock 1,375 feet long to the Eklutna Power Plant on the Knik arm. The plant consists of two 15,000-watt vertical shaft generators, each driven by 21,000 horsepower reaction turbines. Generators and electrical equipment are housed in a steel and concrete building. From the Eklutna plant, a 9-mile 115 kilovolt transmission line runs north to Palmer and another line 32 miles long runs southwest to Anchorage.

Eklutna Power Plant was back in service 20 minutes after the earthquake. High-voltage circuit breakers connecting the plant to the transmission lines had been damaged but were quickly bypassed by temporary jumpers. A snow slide knocked out the Palmer transmission line, but the Anchorage line remained in operation.

At midnight the water supply to the plant ceased, owing to damage in the intake structure at Eklutna Lake which allowed a large earth plug to build up in the waterway. The earth plug was gradually dissipated by working water through the plant, and for the next 6 weeks the plant was operated on an emergency basis. Periodic shutdowns were made to remove sand and rocks and to clean out the cooling water system.

Subsequent inspections of damage showed that the intake section had been damaged where it was underlain by alluvial silts, sands, and gravels that surround Eklutna Lake. The earthquake had caused settlement of the alluvium which developed tensional forces and caused separation up to 2 inches wide in many of the joints of the precast concrete pipe used for the intake conduit in the alluvial materials.

Eklutna Dam is an earth and rockfill structure with wood and steel piling core walls, and has a gated spillway with 19 hand-operated wooden gates supported by reinforced concrete sheet piling piers resting on a concrete base slab. After the earthquake a 3/4-inch wide crack running along the gate seal at the upper end of the spillway was observed. The spillway slab had also had the material washed out from underneath. Because the damaged spillway cannot resist safely the water pressure at the gates, the gates will be kept open until the structure is repaired or replaced. A new dam will be built downstream, because subsequent investigation indicated foundation materials under the present dam are similar to those which caused slide failures in Anchorage. Moreover, it will be cheaper to build a new dam than to make repairs to the old one.

The tunnel and spillway, leading from Eklutna Lake through the mountain to the power plant on the Knik arm, suffered very little damage, and most of the damage incurred was due to scouring caused by the sand and gravels being carried from Eklutna Lake through the conveyance system.

On the Knik arm the power plant and the tailrace channel are on the alluvial deposits bordering Knik arm. These deposits compacted severely during the earthquake, and the resulting settlement damaged the tailrace channel.

The power plant was set upon piles driven through the alluvium and bottomed upon underlying bedrock consisting of graywacke. Although the alluvial material settled under the plant, possibly separating completely from the bottom of the floor slab, the plant suffered little damage, and the piles performed successfully during the earthquake. No serious damage was done to the machinery and electrical systems.

By and large, it can be said that the Eklutna Project performed well during the Alaskan earthquake. Even so, the estimated cost of repairs to the intake structures, the dam, and the tailrace channel, and other miscellaneous items, amounts to approximately $4 million. The Bureau has approximately $31 million invested in the Eklutna Project which means that the earthquake damage amounts to about 13 percent of the original cost. Based on initial 9 years of operation prior to the earthquake, it was anticipated that payout of the project would occur 9 years earlier than the 50-year period normally adopted by the U. S. Bureau of Reclamation for such projects. As a result of the earthquake, it is now anticipated that the revenues will be barely sufficient to return all costs to the Treasury with interest during a 50-year period.

Miscellaneous

Approximately 150 miles of single track Alaska railroad from Seward to Fairbanks was severly damaged. The remaining 320 miles received only negligible damage, approximately 121 miles from Healy to Fairbanks remained in use. The Department of Interior has estimated it will cost $24 million to completely repair all the damage on the railroad.

The highway from Seward to Anchorage was blocked by four major snow slides, 17 damaged bridges, and large cracks and washouts.

The bulk oil plant at Seward with 40,000 barrels of petroleum product was destroyed by fire.

All major airports remained operational, but some suffered minor to moderate damage. Total damage to airports exceeded $1 million.

CHAPTER V. REHABILITATION MEASURES

The devasting force of the Alaskan catastrophe left stricken communities with the problem of digging out of the wreckage and starting restoration of necessary facilities. The rehabilitation measures required were of such magnitude that immediate outside assistance was required. This chapter discusses the rehabilitation measures taken.

Damage Repair

During the first 48 hours, following the earthquake, while the Federal Government was organizing its relief effort, the military components in Alaska initiated emergency relief measures to supplement state and local efforts.

The Command Post of the Alaska Military Command at Anchorage became the center through which communications were re-established between Alaska and Washington and between state and city civil defense. Military communications personnel and signal battalions worked with civilian companies to restore communication service. Military water trucks and water purification units were made available where needed. A massive airlift consisting of C-123 military transports were used to carry relief supplies and equipment to Seward, Valdez, Kodiak and other isolated communities. Elmendorf Air Force Base and Camp Richardson furnished meals and lodging immediately after the quake.

In response to a request from Anchorage, military authorities were assigned to assist in security and travel control. Military personnel, including doctors and nurses, were also assigned for emergency work in nearly all of the affected areas.

Because of the short construction season and the severity of the Alaskan winters, reconstruction project planning required careful coordination to insure completion of necessary work prior to the onset of winter. These plans were developed by Federal, State, and local officials, in cooperation with the staff of the Federal Reconstruction and Development Planning Commission. The following steps resulted from the coordinated efforts: (1) the responsible agencies made emergency repairs to utilities and highways; (2) extensive geology and soils studies were made to determine where these facilities should be permanently reconstructed; (3) the projects were designed; and (4) finally, proposals from potential contractors were evaluated and contracts awarded. Because of the short construction season, time required for almost every step was greatly accelerated.

Top priority was given to the installation of water and sewer lines, and this work was started within a few days after the earthquake, with permanent reconstruction of all severely damaged water lines scheduled for completion by early fall. Airports and boat facilities were assigned priority second only to that of water and sewers.

All highways, except for the ones on Turnagain Arm and along Copper River, have been temporarily repaired and can handle normal traffic loads at reduced speeds. Permanent highway reconstruction has been scheduled over a three-year period and is estimated to cost about $65 million. Alaska railroad reconstruction is being accomplished by internal resources, by contract, and through the Corps of Engineers.

Repair of most schools was completed in time for the 1964 fall term. Double shifts may be necessary in two or three schools thi fall.

Federal and State reconstruction efforts have incorporated urban renewal project planning for Anchorage, Cordova, Kodiak, Seward, Seldovia, and Valdez. These urban renewal projects will provide earthquake damaged communities with better land utilization, the removal of blighted area, and more effective traffic patterns. Urban renewal applications and planning procedures, which normally take 18 months to 2 years to process, are being processed in 2 or 3 months.

Financial Aid for Local Agencies

In order to maintain essential local and state services after the earthquake, the President requested a $22.5 million authorization for new transitional grants for the period through June 30, 1966. This was to compensate for the large loss of tax revenue resulting from property damage. Congress increased the President's request for this grant from $22.5 million to $23.5 million to allow for the loss of revenue by the Anchorage School District. On May 25, 1964, the President requested a total amount of $52.2 million to meet various program requirements in Alaska. The total amount finally appropriated by the Congress was about $41 million, after major deletions of $5.2 million for the Alaska railroad, and $5.6 million for the Corps of Engineers small boat harbor expansion projects.

Legislation, which amended the Alaska-Omnibus Act and provided additional and, in most cases, new types of assistance for highways, urban renewal, debt adjustment, harbors, and disaster loans were presented to the Congress on May 27, 1964, by the Presiden

The new legislation provided for an increase in the federal share of reconstruction cost from 50 percent to 94.9 percent on federal-aid highways. The new legislation also authorized the

Corps of Engineers to modify previously authorized civil works projects, if modification was needed to overcome the adverse effects of the earthquake.

The Farmers Home Administration, the Rural Electrification Administration, and the Housing and Home Finance Agency were authorized to adjust the indebtedness of some of their borrowers thereby enabling them to cope with earthquake losses. Another amendment to the Omnibus Act authorized the Administrator of HHFA to enter into construction for grants not exceeding $25 million for urban renewal projects in the Alaskan disaster area. Legislation also authorized purchases by the Federal Government of up to $25 million of State of Alaska Bonds, or the loan of $25 million to the State. Additional changes to urban renewal legislation increased the federal share from 75 percent to 90 percent of the net project cost. The legislation also provided authority for federal grants to help adjust or retire the outstanding mortgage obligation on the one- to four-family residences which were severly damaged or destroyed by the earthquake. This legislation has a limiting provision that federal funds cannot exceed $5.5 million, and that they must be matched on a 50-50 basis by State funds. This legislation was signed by the President on August 19, 1964.

Financial Aid to Privately Owned Facilities

Federal agencies responded to this disaster by liberalizing normal disaster aid policies. Wherever possible, Washington offices authorized immediate local processing and/or approval in order to reduce time normally required for such repairs. Small Business and Rural Electrification Administration, Farmers Home Administration, and the Bureau of Commercial Fisheries are providing $60 to $70 million in low interest rate loans. The Federal National Mortgage Association and the Veterans Administration agreed to release from further obligation mortgages on destroyed property. Borrowers were required to make a token payment of $1,000 in order to qualify for this relief. The Small Business Administration granted forebearance on principal and interest payments for one year, and on principal for another four years. It also provided for the first time amortized loans on a 30-year basis, using the 20-year maturity plus a 10-year extension for orderly liquidation.

The Small Business Administration agreed to make loans up to 30 years at 3 percent interest for owners who wish to rebuild. These loans could also include the $1,000 token payment required under FNMA and VA mortgage forgiveness programs. Farm Home Administration also made available 3 percent emergency housing loans to rural residents, and offered to adjust indebtedness of the borrowers. Some of the larger lending institutions indicated, informally, that they would be willing to settle some of their outstanding mortgages on a case-by-case basis. The Internal Revenue Service extended the April 15 deadline for application of tax rebate against the 1963 income tax, or against the 1964 estimated tax.

In Retrospect

Both local and federal governmental agencies, private interests and individuals moved with remarkable alacrity in solving the problem of rehabilitation. In order to do what was needed in the time allowed, it was necessary to develop a plan, obtain necessary financing, and put the plan into operation. The accomplishment of all these things within a few months required new legislation and a drastic acceleration of the governmental processes normally required for such matters.

Because of our greater population, the problems of earthquake rehabilitation could be much greater in California. It would appear prudent for California to think about what this state would do after a large earthquake and have a general plan of action in readiness for such a catastrophe. The procedures used for rehabilitation in Alaska should not be considered as a precedent and guide, because they necessarily were developed on the spot for immediate solution of the problems at hand.

CHAPTER VI. RESULTS OF INVESTIGATIONS

Although a number of investigations were made of various aspects of the Alaskan earthquake, the results of the technical investigations are of most interest to the Department. This chapter summarizes the results of the technical investigations.

Structural Failures

A summation of investigations on structural failures gathered from reports and articles, through personal meetings, and from presentations to various professional societies, is presented in the following:

System Behavior

When a structure vibrates from ground motion, the structural frame, shear walls and exterior walls all react dynamically together as a system. Failure of the designer to recognize this fundamental principle can result in serious damage, as dramatically shown by the failure of rigid precast concrete exterior walls on a flexible frame in the J. C. Penney building. Other structures using flexible frames and shear walls resisting horizontal forces as a unit, experienced initial failure of the more brittle shear walls, thus exposing the frames to the entire vibrational load. This type of failure has led to discussions on the amount of resistance the frame should be designed for in combination with the shear walls. Mr. John J. Driskell, Consulting Structural Engineer, in a letter to the Engineering News Record (June 11, 1964) stated, "A critical lesson to be learned from these examples is that reliance on shear walls in a strong-motion, long-duration earthquake, to provide the major resistance to lateral forces, leaving a partial-capacity moment-resisting frame to serve as a 'second line of defense', is to ignore evident facts, made crystal clear in the Anchorage earthquake. The shear walls will predictably be destroyed in the first few major excursions, leaving the moment-resisting frame to somehow resist the remainder of the duration of the strong motion".

Bracings and Rigid Connections

It was found that a number of failures were results of negligence or improper design in providing bracings and rigid connections to transfer the lateral forces to the proper members for resistance. West Anchorage High School supposedly was designed in accordance with UBC Zone III standards, yet the collapse of the structure was attributed partly to improper bracings and connections. Another example was an industrial structure where its precast members failed principally because the connections tying these elements together were inadequate.

Relative Column Stiffness

In the Cordova Building, the stiffening of one column in a group to resist lateral forces was disastrous because this single column had to resist the full lateral load until it failed, or became overstressed, before any of the load could be transferred to other columns.

Flexible Roofs

There were some roof damages, especially in large area structures, such as one story warehouses, built with concrete walls and wood roofs. The roof deck was too flexible for the relatively rigid concrete walls and was unable to function properly as a horizontal diaphragm.

Foundation Design

It was found that most structures built upon firm foundations, or founded upon piles, survived the earthquake with little or no damage. This is especially true for rigid structures where very little elastic deformation is assumed, and therefore base shear becomes a critical consideration in the design.

Elevated Mass Systems

Structures such as the power plants at Chugach and Elmendorf had elevated loads that added to the inertial forces developed during vibration. Because these added loads were in a critical location, they were a contributing cause of connection damage and column buckling. Unnecessary parapet walls, heavy suspended lighting fixtures, and some architectural ornamentations have the same effect during an earthquake as an elevated mass system. In addition, veneers and ornaments on walls of a flexible nature are readilly loosened during vibration and create unnecessary hazards.

Light Mass Structures

Because of the basic reasons stated in Chapter IV, light mass structures, such as wood frame buildings designed as rigid structures, fared well during the earthquake. Obviously, heavy mass structures, such as masonry, probably would have fared as well, if properly designed or constructed. However, this study indicates that, if construction materials are not a prime consideration in rigid structures, light mass structures are better than heavy mass structures because the earthquake forces and base shear forces are not as great in lighter structures. Because of the smaller forces, foundations cost less, and smaller base members and connections can be used in the lighter structures.

Irregular Shape Structures

"L" and "T" shaped buildings and other irregular shape structures were susceptible to damages from ground motion because the wings were not separated to act as individual units, or they were not designed properly to handle forces produced from the differences in natural frequencies set up within the structure.

Exposure and Pounding

Some damages were incurred when adjacent structures with different natural periods of vibration pounded together during the earthquake. This type of damage can be reduced by providing adequate clearance between the structures. Pounding also may damage separated wings of irregular shape structures, discussed above, unless properly designed.

Importance in Details

It was found that a large number of the damages could have been avoided if sufficient lengths for splicing of reinforcement steel had been made, or hooks had been detailed for bonding, or anchorage or better placements of column ties were specified. Although not evident in the investigation, it is probable that some failures could have been avoided by specifications which provide for better control of concrete mixes and grading of aggregates or provide for items such as grouting of hollow concrete blocks.

Because it is difficult to attain the skill of workmanship and closeness of inspection required to produce good quality concrete block construction, it appears advisable to avoid this type of construction in earthquake resistant structures.

Construction Practices

Some of the engineers have pointed out that because of the short construction season, generally April 15 to October 15, contractors were forced to bypass certain standard construction practices in order to meet completion schedules. Obviously, this often resulted in an inferior finished product, and evidence indicates that poor construction was a significant factor in earthquake damage.

The absence of grout in hollow concrete block walls and the absence of reinforcement in some of this type of construction is the result of inadequate inspection. In reinforced concrete structures, the lack of proper steel placement and insufficient lengths for dowels and splices, also indicates faulty inspection. Evidence of poor concrete mixes indicates lack of field testing and quality control during construction. Structural damage resulting from failure of dirty cold concrete joints, indicates lack of enforcement of good construction practices.

Results of Soils and Foundation Engineering Investigation

The most completely documented studies of soils and foundation engineering were contained in reports prepared by Shannon and Wilson, Inc., of Seattle for the Alaska District of the U. S. Army Corps of Engineers. These reports covered investigations of the Anchorage landslides, the submarine slides at Seward, and investigation of a new townsite for Valdez. Although there were numerous other reports of soil failures, the Shannon and Wilson reports contain the only quantitative information that the committee could obtain for study. There does not seem to have been any other major reports made of soils and foundation engineering.

Soil Studies

The field investigations conducted by Shannon and Wilson, Inc., consisted of borings of a variety of types supplemented by trenching, geologic mapping, undisturbed soils sampling, field vane shear tests, field pore pressure measurements. Also included as a part of these studies were geophysical investigations and geological investigations, consisting of mineralogical and paleontological studies. In addition to the field studies, a laboratory testing program was conducted to classify and identify the various soils and to determine their engineering properties. Considerable attention was paid to relative density of cohesionless soils, and sensitivity of clays and silts.

Special laboratory tests were developed during the course of investigation. These special tests included torsion shear tests, laboratory vane shear tests, dynamic modulus measurements, shear strength under pulsating loads, and physicochemical analyses of soils.

In addition to the laboratory test programs, model studies were made at the University of California at Berkeley to study the mechanics of failure of the Turnagain slide. The Berkeley tests successfully and graphically depicted the progressive nature of the sliding in the Turnagain area.

Also conducted at the University of California were some very interesting dynamic strength tests. During these tests, critical soils were subjected to pulsating loads and/or different combinations of principal stresses. It was found that these critical soils would fail at stress levels much lower than indicated by conventional static tests. Quoting from Shannon and Wilson in their report on the Anchorage slides "...the dynamic loading tests on undisturbed samples of very sensitive clay from the Turnagain area indicated that under cyclic loading conditions failure would occur after 50 to 60 cycles at a stress level equal only to 55 percent of the static strength". The dynamic strength tests conducted at Berkeley also showed that liquefaction was possible even in relatively dense sands when subjected to the sufficient number of stress reversals. Confining pressure and degree of saturation have been demonstrated to be major environmental factors in this relationship. Shannon and Wilson in their report on the

Anchorage slides state "...similar tests on samples of sand reconstituted to a condition thought to be representative of that of the in-situ material indicated that complete liquefaction would occur after 60 cycles of stress at a frequency of 2 cycles per second with a shear strength of about 0.25 to 0.30 tsf. Failure of the specimens in these tests occurred very abruptly with little or no strain prior to actual liquefaction and failure of the sample".

In summarizing the knowledge of materials involved in the Anchorage slides it was found that the surficial material underlying the city of Anchorage, the Naptowne outwash, was comprised of relatively dense gravelly sand. The underlying Bootlegger Cove formation could be divided into three zones from the standpoint of soil characteristics. It consisted of an upper zone of stiff clay with unconfined compressive strengths greater than 0.5 tsf. The middle zone contained very sensitive silty clays, and fine sands and silts having unconfined compressive strengths ranging from 0.2 to 0.5 tsf, and with a sensitivity of the clays ranging from 30 to 50. The lower zone was a fairly stiff competent clay with unconfined compressive strengths greater than 0.5 tsf.

Mechanics of Failures

A surprising fact about the landsliding in Anchorage was that before the earthquake most of the original bluffs and slopes were not considered to be either too steep or too dangerous. Ordinary methods of computing stability, using static shear strength values, would not have indicated trouble and have been shown in this disaster to be misleading.

According to the reports, most of the slides did not develop until after the first minute or so of shaking, and they stopped when the shaking stopped. The landslide damage was most noticeable in development of a "graben" or down dropped block structure that formed when the ground mass moved horizontally. These "graben" developed in the head or just beyond the head of the slide. Except at Turnagain little damage was sustained by structures within the slide mass although all access and all utilities were severed by the movements.

The Shannon and Wilson report concluded that slide failures generally developed in zones of maximum shear strains at the upper boundary of the weak and sensitive clays and by liquefaction of loose, saturated or nearly saturated sands. Where no sand layers were present, failures occurred as a result of shear stress reversals under pulsating loads, of from 1 to 2 cycles per second, which resulted in remolding the sensitive clay.

The "L" Street and Fourth Avenue slides were considered to be primarily liquefaction failures. The failures at First Avenue and Government Hill were related to oversteepened slopes created by previous excavations at the toe. The Government Hill failure was by wedge action which might have been caused primarily by failure of sensitive clays, although some sand liquefaction was

also suspected. At Romig Hill the movement was a conventional rotational slide; whereas the bluffs along Ship Creek and Chester Creek appear to have been marginal in stability even before the earthquake. It is interesting to note that an old slide plane was discovered in the First Avenue slide, and that the Fourth Avenue slide area had been recognized for some time as a slide area.

The landslide at Turnagain was unusual in that the failure developed progressively as a sequence of retrogressive rotational slides combined with horizontal sliding of massive, intact blocks. These major movements are reported to be due to severe remolding of sensitive clays. Local movements continued for several days after completion of shaking and major settlement is expected to continue for years due to reconsolidation of the sensitive clays.

Landslide failures can be divided into these three general categories:

1. Those due to liquefaction.

2. Those due to remolding.

3. Those due to unbalancing the initial static equilibrium.

Remedial Measures

Recommendations made for repair and rehabilitation of the landslides included:

1. Fourth Avenue - Combination of slope regrading, improvement of subsurface drainage, and construction of earth buttresses at the toe of slope.

2. "L" Street - Combination of slope regrading with gravel buttressing in selected areas.

3. Romig Hill - Minor regrading.

4. First Avenue - Slope flattening, minor buttressing, and improved subsurface drainage.

5. Government Hill - Considerable slope flattening considered adequate, unless buttress needed to hold up excavated toe.

For the Turnagain area, however, there was some doubt as to the best remedial treatment. Accordingly, the recommendation was made that additional field tests would be desirable to test the efficiency of explosives to remold the sensitive clays and thereby develop a buffer zone which would permit reclaiming a large part of the expensive Turnagain residential development. The tests would attempt to develop a delayed-sequence firing system, the optimum combination of charges, and the most efficient spacing of holes. Sand drains were to be included to facilitate the ensuing reconsolidation. No final report of this work has been received but by

verbal inquiry it has been learned that only partial success has been achieved. A new test program involving the use of electro-osmosis as a mechanism for stabilizing the sensitive clay is now being considered.

Results of Landslide Investigations

The studies of the Anchorage landslides show that analytical methods now used, which rely on use of static equilibrium and static strengths in estimating slope stability, are inadequate when dynamic forces from an earthquake are involved. For adequate analysis, the response of the soil mass to dynamic forces must be determined. For this, it is necessary to know the characteristics of the earthquake such as: the duration of the shaking; and amplitude, period, frequency; and acceleration of the ground motion. Shannon and Wilson developed a rather simple, but crude, method of analysis in their attempts to determine corrective methods of treatment. Although their approach is not completely desirable, more sophisticated analyses, which appear promising, are being worked upon at the Berkeley campus.

It is clear that realistic factors of safety must consider both shear strength failure and excessive deformations.

Submarine Slides

Submarine slides which followed the Good Friday earthquake have been reported as the major cause of damage at both Valdez and Seward. At the latter city, the waterfront, and the Forest Acres residential area north of Seward, have been badly damaged. At Valdez most of the waterfront was destroyed.

The submarine landslide at Seward was carefully examined by Shannon and Wilson, Inc., for the Alaska District Corps of Engineers. They report the geological profile composed of three basic units: Upper sand and gravel deposits of alluvial and glaciofluvial materials ranging from fine sand and silt, to boulders; a middle deposit of silty, medium-to-very fine-grained uniform sand interbedded with clayey silt and occasional layers of gravel and coarse sand; and lower sand and gravel deposits denser than the upper stratum and interbedded with glacial till. Bedrock was beyond the range of penetration of the seismic surveys used.

At Seward the submarine slides were reported as the conventional rotational type which subsequently liquefied and became flow slides moving large distances. The slide debris was distributed as a thin layer over the floor of the bay at depths too great to detect its presence. The failure was considered to be progressive and successive slides developed as the earthquake continued.

Results of Geological Investigations

Most of the geologic investigations that took place in Alaska after the earthquake occurred were conducted by the United States Geological Survey. Complete results of their investigations

have not yet been compiled into report form. The preliminary work of the USGS, in addition to providing an excellent report of damage in Alaska and related earthquake phenomena, indicated the following geologic factors affecting damage.

Avalanches and Rock Slides

The earthquake caused thousands of snow avalanches and rock slides. The principal areas of occurrence for these slides were the Kenai Mountains, the Chugach Mountains and the islands in Prince William Sound. Snow avalanches were noted as far away as 150 miles.

Compaction of Sediments

Poorly consolidated alluvial glaciofluvial, and geologically young sediments were compacted by the action of the earthquake Although this phenomena was noted in a number of places, it was specifically noted in Homer Spit and Portage.

Consolidation of sediments combined with tectonic subsidence was responsible for damage encroaching water lines at Homer Spit and caused inundation of approximately 5 miles of right-of-way of the Alaskan railroad in the Portage area. Settlement of approaches was noted at a number of bridges. Damage from approach settlements was particularly noticeable where the bridge spans placed on piles settled very little in relation to approach structures.

Landslides

The types of materials that experienced settlement, the poorly consolidated, alluvial and glaciofluvial deposits, were the ones in which most of the destructive landslides developed. These include the Anchorage landslides and the landslide at Potter that damaged the Alaskan railroad.

Lurching

Lurching effects in the unconsolidated deposits were also noted on some structures, and some displacement of highways and piles are attributed to this cause.

Geologic Conditions Related to Damage

It was obvious from observation of the damage in Alaska, that those buildings on bedrock generally suffered less damage than those on the unconsolidated deposits. It was pointed out by the USGS that large concrete buildings which were on bedrock at Whittier, approximately 40 miles from the epicenter, received less damage than similar structures at Anchorage on outwash gravels and clays 75 miles from the epicenter. Cordova, underlain by bedrock also was about the same distance as Anchorage from the epicenter of the earthquake, but suffered little structural damage from shaking.

In Anchorage it was noted that structures underlain either by a thin layer of gravel which covered the Bootlegger Cove formation, or underlain by silt, were much more severely damaged than those underlain by thicker layers of gravel.

Submarine Landslides

It is suspected that more submarine slides occurred in deltaic materials deposited in the narrow fiords around Prince William Sound than were observed. These types of failures were reported at Valdez and Seward, but because the other fiords are uninhabited, no information is available. There is ample evidence that the fiord deltas can be unstable under earthquake conditions, and considerable care should be exercised in future development of town sites, and dockage areas on the shorelines of such deposits.

CHAPTER VII. CONCLUSIONS AND RECOMMENDATIONS

The review of reports on the Alaskan earthquake damage indicates that structures can be built to satisfactorily resist forces from a major earthquake, provided they are properly conceived, designed and constructed. There is room for improvement, however, and better information is needed about the following: response spectra for buildings and earth masses; earthquake forces, the weakening effects of earthquakes on soil and rock masses, and the interrelationship between the structure, its foundation, and its geologic setting.

The yardstick used by seismologists to measure earthquakes, the magnitude rating, has little significance to the designer, and, therefore, earthquake indices more useful to the designer should be developed. The designer also needs to be provided with better statistical data on the probability, frequency, and type of earthquake anticipated so that he can evaluate better the risks involved.

It should be emphasized that there are dissimilarities between Alaska and California, and discretion must be used in drawing comparisons between what happened in Alaska and what might happen in California. Although information obtained from the Alaskan earthquake has added to our knowledge of earthquakes, particularly in the field of structural and soils engineering, there are still large voids which can be filled only be continuing studies of California earthquakes and their related problems.

Conclusions drawn from the Alaskan earthquake and recommendations for making the State Water Project more resistant to earthquake damage are presented in the following. Although the recommendations were formulated for application to the State Water Project, they have a general application to other activities of the Department.

Conclusions

Property Damage

1. The initial publicity on the Alaskan earthquake gave the impression that south central Alaska experienced nearly total destruction. This impression was inaccurate, and competent observers estimate that even in Anchorage, the hardest hit community in terms of dollar value of property loss, approximately 90 percent of the structures remained relatively undamaged.

2. Although there are exceptions, damage to property can be classified into four broad categories: (1) damage caused by landslides or submarine slides; (2) damage caused by structural failures resulting from shaking; (3) damage caused by tsunamis and seismic

sea waves rushing into coastal communities; and (4) damage to structures caused by settlement of foundation materials. Of the four general categories of damage the landslides and submarine slides were responsible for the greatest property loss; whereas the tsunamis and seismic sea waves were responsible for the greatest loss of life.

Soils Failures

1. Investigations of Anchorage landslides indicated that although the materials in the slides probably would be stable under normal conditions, earthquake vibrations caused liquefaction of sands or remolded highly sensitive clays, reducing the strength of the materials to the point of failure. The unusually long duration of shaking was a major factor in slide failures.

2. The earthquake vibrations caused settlement of soils. This settlement, which probably resulted from compaction or liquefaction, caused considerable damage.

Structural Failures

1. Failures of structures from shaking can be attributed to the following causes: (1) the designer's lack of complete understanding of the complexities of earthquake-resistant design; (2) failure to build the structure as it was designed; and (3) poor construction practices that result in structural weakness.

2. Structures, particularly long period structures, can experience severe damage at distances up to 75 miles from the epicenter of a great earthquake, especially where foundation conditions amplify ground motion.

3. Structures with long periods of response generally suffered more damage from earthquake vibrations than those with short periods of response.

4. Greatest damage was experienced by structures in areas underlain by poor foundation conditions. Structures founded upon bedrock generally suffered the least damage.

5. Masonry and precast concrete construction appeared to be particularly susceptible to vibration damage. Masonry failures were due primarily to poor construction; precast concrete failures were due primarily to faulty connections.

Earthquake Duration

The duration of the earthquake, estimated from 4 to 6 minutes, was unusually long.

Additional Hazards to Coastlines

In addition to the usual earthquake hazards, coast lines of seismically active areas are exposed to additional damage from destructive seismic sea waves, submarine slides, and permanent effects of changes in shoreline caused by regional tectonic warping.

Tectonic Uplift and Subsidence

The crustal warping that accompanied the earthquake caused tectonic uplift or subsidence that affected an area currently estimated to be 83,000 square miles, equal to about half the area of the State of California.

Rehabilitation

In examining the rehabilitation measures that are necessary after a disaster of this magnitude, it is obvious that a predetermined course of action should be available prior to such a disaster. Emergency procedures taken in Alaska for rehabilitation and restoration should not be considered as a precedent or a guide.

Recommendations

The recommendations made as a result of this investigation are directed specifically toward design and construction of the State Water Project, but the recommendations have general application to the development of earthquake-resistant structures throughout the State.

Soils Engineering

In soils engineering investigations it is recommended that:

1. Techniques for stability analyses of embankments, cut slopes, and natural slopes should be revised to include consideration of strength reduction in soils due to pulsating loads and accompanying plastic deformation or liquefaction. Two kinds of safety factors must be defined in these types of analyses; one for actual shear failure or flow, and one for the detrimental deformation of the material.

2. To aid in identifying materials susceptible to severe loss of strength during earthquakes, it should be a standard Department procedure to make relative density tests on cohesionless materials and sensitivity tests on clays during preliminary soils test programs.

3. In order to make meaningful use of dynamic strength tests of soils, the soils engineer must be provided with an estimate of the number of load pulses that might be expected from earthquakes in California. This should be done by synthesis of data from existing seismograph records. In addition, methods need to be developed for determining response of soils to the ground motions anticipated.

4. It is recommended that where foundation materials are comprised of either loose, cohesionless soils prone to settlement for vibration, or of materials subject to loss of strength from pulsating loading, piles or other deep type of foundation be used for structures.

Structural Engineering

In the design of earthquake-resistant structures for the State Water Project it is recommended that:

1. Supervisors responsible for design of earthquake-resistant structures should continue to make sure that design criteria, the design, and any revision to the design are made by engineers who are specialized in and have a good understanding of the complexities of earthquake-resistant design.

2. When positions whose duties require knowledge of the principles of earthquake resistant design are to be filled, prospective applicants should be required to demonstrate their proficiency in earthquake resistant design. Present civil service procedures should be modified to include testing the applicant's knowledge of the dynamic response of structures, behavior of structures under submergence and other aspects of earthquake resistant design, in addition to other skills normally tested in the examination process. It should not be assumed that the "core classification" always will provide personnel with the desired experience and knowledge for the design of hydraulic structures.

3. The existing Uniform Building Code should be considered as the minimum design criteria for structures. In many cases, it may be desirable to incorporate additional provisions into the design. Design supervisors should be responsible for the development of additional criteria and provisions where needed and should make use of consulting board members or staff specialists in developing these additional measures.

4. The designer should continue to pay particular attention to the following items in the design of earthquake-resistant structures: irregular building shape, flexible roofs, wall materials, pounding exposure, elevated masses, and precast reinforced concrete construction.

5. The following design treatment generally should be used for shear walls: For low rigid structures, especially those with box frames, shear walls should be included in resisting lateral forces, because it usually is assumed that no elastic deformation occurs in these types of structures. For tall, flexible structures possessing frame-shear wall combinations, shear walls should not be counted upon for resistance to lateral forces; consequently the frames should be designed to resist all lateral forces.

Construction

For construction, it is recommended that:

1. Efforts to tighten field inspection controls and enforce proper construction methods should be continued.

2. For earthquake-resistant structures, designers should make all construction details clear. Lack of clarity or lack of details on design drawings forces the resident engineer to guess the designer's intention and a wrong guess could prove disastrous. Design drawings should have sufficient detail, so field construction personnel can produce the real intent of the design. For earthquake-resistant structures, details pertaining to lapping lengths, splicing locations and placing of reinforcing steel, and structural bracings and connections, particularly in critical areas should be clearly defined and drawn. The jamming of too many details into one drawing sheet should be avoided, as the resulting clutter can lead to confusion and erroneous interpretation.

3. A standard procedure be established and followed wherein it would be the responsibility of the program managers to bring designers of the structure and the field construction personnel together for briefings prior to construction. In these briefings, the designers should inform construction personnel on critical items requiring special attention during construction. The designers also should brief construction personnel on the design approach and on any unique design principles used. Such a procedure would give construction personnel better insight into the design problems, and would help to ensure that the designer's intent is incorporated in the completed structure.

4. No field revisions should be made in a structure without prior approval of the designer.

5. When an earthquake-resistant structure has been completed, and subsequent modifications are to be made, these modifications should be approved by competent design engineers, preferably the originating design group familiar with the structure.

Engineering Seismology

In the field of engineering seismology, it is recommended that: The designer should be provided with more meaningful information on earthquake hazard and the ground motion for which he should design. It is necessary to continue with the seismic information program in order to learn more about the behavior of California earthquakes. The most important types of instruments are the strong motion instruments which, however, need considerable improvement.

Engineering Geology

In conducting engineering geology investigations in the future it is recommended that:

1. A site for a proposed structure should be considered in the reference of regional tectonic framework as well as the geology in the immediate vicinity of the site. The attitude of "no fault, no worry" in site hazard evaluation is not always true.

2. The designer should be made aware that areas near active faults may be subjected to tectonic uplift or subsidence. It is not possible to accurately predict what the areal extent of such deformations might be, or the magnitude. Because of the unpredictable nature of tectonic deformation, it does not appear that large sums of money should be spent in an attempt to make structures resistant to this type of phenomena. It should be kept in mind by the designer, however, and if opportunities arise to provide some protection against tectonic movements at little extra cost, he should avail himself of these opportunities. Operations and maintenance personnel also should be made aware that crustal warping could seriously affect aqueduct operations.

3. The geologist should impress upon the designer that damage can occur to structures at least as far as 75 miles from major faults, particularly where soils conditions are poor, and the structure under consideration has a long period of response.

4. For site investigations of structures located on the coast line, such as a nuclear power plant, the site evaluation performed by the engineering geologist should take into consideration potential damage from seismic sea waves, submarine landslides, and changes in the coast line elevation caused by an uplift or down warping resulting from tectonic movement. Specific items to be considered are probable sources of seismic sea waves, their effect upon the coast line, local shoreline configuration, the type of off-shore sediments, an evaluation of the possibility of submarine landslides, and the possibility of wave damage caused from submarine slides in the vicinity of the site.

Rehabilitation Measures

In order to be adequately prepared for rehabilitation of the State Water Project in the event of earthquake damage, it is recommended that:

1. The Chief Engineer should have complete authority to take necessary remedial measures to the State Water Project when a catastrophe occurs. Moreover he must have immediate access to adequate sums of capital needed to mobilize the necessary equipment, manpower, and materials needed to put the aqueduct system back into operation. He must have the authority to make immediate decisions on expenditures and mobilization of equipment and manpower without going through procedures normally required for such actions.

2. It is recommended that a committee be formed within the Department and that this committee be assigned the responsibility of (1) identifying the problems involved in making such emergency authorities available to the Chief Engineer, (2) exploring methods by which the necessary emergency authorities can be provided, and (3) recommending action needed to make these authorities available to the Chief Engineer.

3. An effective and comprehensive damage control plan which would clearly outline the action of all organizational functions in the event of a damaging earthquake should be developed. Such a plan should be so clearly defined that field functions would be able to operate during the first few hours after an earthquake without communication with headquarters, and would know how to obtain equipment, men and materials for emergency repairs. Such a plan should also provide for a tentative priority of repairs, so restoration can be made in an orderly fashion without duplication of effort. The plan should also maintain an inventory of the availability of heavy equipment such as that done by the "AGC Plan Bulldozer" and would make this information available to all parties concerned. Although the Department should have the sole authority for conducting repair operations, its disaster plan should be coordinated with the State Disaster Office.

4. In the event of a major earthquake it is conceivable that funds needed immediately to make extensive repairs would exceed emergency funds readily available to the Department. Because the project is operated and owned by the State it would appear that emergency State funds normally available to other public agencies might not be available to the Department.

It is recommended that a committee be formed to look into the matter of emergency financing for repair and rehabilitation. A suggested approach would be to have the Division of Design and Construction and the Statewide Operations Office make a rough estimate of the dollar amount of damage that might be sustained by the aqueduct system during an earthquake. The Staff and Services Management and Legal Staff might explore methods of obtaining the estimated amount of emergency funds required. Upon completion of the study, the committee should recommend the action needed to bring about the amount of emergency financing estimated to be needed.

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